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COMPARATIVE EVALUATION OF FACTORY BUILT HOUSE CONSTRUCTION METHODS VIS-Å-VIS THE TRADITIONAL CONSTRUCTION METHOD ON SITE

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Report Submitted by GINTER Inc.

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Société d'habitation du Québec

COMPARATIVE EVALUATION OF FACTORY BUILT HOUSE CONSTRUCTION METHODS VIS-À-VIS THE TRADITIONAL CONSTRUCTION METHOD ON SITE

Report Submitted by GINTER Inc. to:

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This document was prepared under an agreement concluded on March 23, 1990 between Société d'habitation du Québec and Canada Mortgage and Housing Corporation which together authorized the publication thereof. The ideas expressed herein are solely those of the authors of the document and are not necessarily shared by these Corporations.

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SUMMARY

This study deals with moderate cost housing. Twelve typical systems are selected and compared:

- TRADITIONAL BUILDING METHODS CURRENTLY USED IN QUEBEC: wood frame, bearing masonry, monolithic concrete cast on site;
- MANUFACTURED SYSTEMS CURRENTLY AVAILABLE IN QUEBEC: light panel open framing, stressed skin box panels, composite panels with rigid insulation, modular homes, permanent formworks using rigid insulation;
- MANUFACTURED SYSTEMS LIKELY TO BECOME AVAILABLE IN QUEBEC: sandwich panels, prefabricated concrete panels;
- MANUFACTURED SYSTEMS USED ABROAD AND OF INTEREST FOR QUEBEC: light wood frame panels assembled by automation, and manufactured modules with structural steel edges.

The comparison is based on a common denominator consisting of three series of plans that correspond to the main spans of the framing in the systems studied. Each series presents a specific plan for each of the following three types of dwelling: single-detached units, row housing, low-rise multi-family housing.

On the basis of this common denominator, each system is evaluated using the CRITERION OF ECONOMY, i.e., the unit construction cost (m^2) and the following TECHNICAL AND QUALITATIVE CRITERIA: scope of the system, extent of industrialization, duration of work, architectural flexibility and quality of joints.

Based solely on the criterion of economy, MODULAR HOMES win in the case of single-detached homes while WOOD FRAMING and its prefabricated off-springs (OPEN FRAMEPANELS AND COMPOSITE PANELS WITH RIGID INSULATION) win in the case of row and multi-family housing. Two innovative industrial technologies follow closely behind: SANDWICH PANELS (meccano assembled on site) and PERMANENT FORMWORKS (hybrid). The superiority of manufactured systems is obvious based on the tehnical and qualitative criteria.

Manufactured construction systems thus offer a valid alternative of superior quality to traditional construction, the cost of which seems to be partly "protected" by the security it represents in the eyes of builders, promoters and labour in general. These systems provide promising competition in view of the fact that an increase in the market would enable them to amortize even more quickly the investment in production equipment, and thus reduce costs to a level at which traditional methods would be unable to surpass them.

SOMMAIRE

L'étude vise le logement à coût modéré. Douze systèmes représentatifs sont sélectionnés et comparés:

- LES METHODES DE CONSTRUCTION TRADITIONNELLES PRESENTEMENT EN VIGUEUR AU QUEBEC: l'ossature de bois, la maçonnerie porteuse, la béton monolithe coule in situ.

- LES SYSTEMES USINES PRESENTEMENT DISPONIBLES AU QUEBEC: les panneaux légers à ossature ouverte, les panneaux caissons à parois contraintes, les panneaux composites avec isolant rigide, les maisons modulaires pré-usinées,les coffrages permanents à base d'isolant rigide.

- LES SYSTEMES USINES PROSPECTIVEMENT DISPONIBLES AU QUEBEC: les panneaux sandwichs, les panneaux préfabriqués en béton.

- LES SYSTEMES USINES EN USAGE A L'ETRANGER ET PRESENTANT UN INTERET POUR LE QUEBEC: les panneaux légers à ossature de bois assemblés par automation et les modules usinés à arêtes structurales en acier.

La comparaison se fait à l'aide d'un "dénominateur commun" constitué de trois séries de plans correspondant aux principales portées atteintes par la charpente des systèmes étudiés. Chaque série présente un plan spécifique pour chacune des trois densités au programme: unifamilial détaché/unifamilial juxtaposé/multifamilial horizontal.

Sur la base de ce dénominateur commun, chaque système est mesuré à l'aide du **CRITERE D'ECONOMIE,** représenté par le coût unitaire (m2) de construction, et des **CRITERES TECHNIQUES & QUALITATIFS** suivants: l'amplitude du système, le degré d'industrialisation, la durée des travaux, la souplesse architecturale et la qualité de joints.

Au niveau du critère d'économie, les **MAISONS MODULAIRES (volume usiné)** l'emportent dans le cas de l'unifamilial détaché alors que l'**OSSATURE DE BOIS** et ses dérivés préfabriqués **(PANNEAUX A OSSATURE OUVERTE ET PANNEAUX COMPOSITE AVEC ISOLANT RIGIDE)** dominent l'unifamilial juxtaposé et le multifamilial horizontal. Deux technologies innovantes et industrialisées suivent de très près: les **PANNEAUX SANDWICHS (meccano assemblé in situ) et les COFFRAGES PERMANENTS (hybride).** Au niveau des critères techniques et qualitatifs, la supériorité des solutions usinées est évidente.

Les systèmes de construction industrialisés offrent donc une solution de rechange valable et qualitativement supérieure à une construction traditionnelle dont les coûts semblent "protégés" par l'aspect sécurisant qu'elle présente aux yeux des constructeurs, des promoteurs et de la main-d'oeuvre en général. Ils livrent une compétition prometteuse si l'on tient compte du fait qu'une augmentation du marché leur permettrait de fractionner encore plus l'amortissement de l'investissement en équipement de production et, de ce fait, de réduire les coûts à un niveau que le traditionnel ne serait plus en mesure de combattre.

1. INTRODUCTION

This report was prepared to establish a systematic comparison between the traditional building method and manufactured and even industrialized systems in the field of moderate cost housing. The comparison was drawn to provide food for thought for decision makers (builders, promoters, manufacturers, government or para-governmental organizations) in the area of residential construction in Quebec.

First and foremost the study is an attempt to characterize the potential which each of the systems studied represents for the construction of housing in Quebec as pertains to the single-family detached model, row houses, and the low rise multi-family housing.

The goal of the comparison is to objectively point out the features which distinguish one system from another and is definitely not to identify a "grand champion": a system is only advantageous if it is pertinent in relation to the project context of the study. The fact is that since the contexts are multiple and variable, no system can include all to the same degree.

The data presented are from November 1990. It is the authors' wish that the study be updated each year on one hand to take into consideration the fluctuations in cost, and on the other hand, to adjust it so as to include improvements which manufacturers will make in their systems; any new systems which arrive on the market may be included.

2. OBJECTIVES

The study is financed by Société d'habitation du Québec (SHC) and the Canada Mortgage and Housing Corporation (CMHC); responsibility for the study was given to GINTER Inc. subsequent to a tender call by SHC.

SHC and CMHC set forth the following three objectives as a point of departure (#1):

"A- To demonstrate, in a neutral manner, the possibilities offered by technological innovations making use of various "factory built" methods;

B- To illustrate, in terms of advantages and disadvantages, the new concepts;

C- To evaluate their execution cost and to assess their qualities considering economic, technical and physical factors in relation to the traditional on site building methods".

In the case of Objective "A", it appears that the demonstration of the possibilities of a system would, of its own, produce interesting topological variance but which would be difficult to compare; the specific characteristics of one particular system make it possible for the latter to easily execute a function which would penalize another system. It is preferable to compare the various systems using the same model plans; this has the advantage of making them easier to compare and of showing their flexibility.

As for the other possibilities offered by the systems, they are numerous in most cases and it will probably be necessary to leave the task of articulating them up to the architects' imagination, once the advantages of the systems have been articulated.

The advantages and disadvantages which are to be identified under Objective "B" may well provide ammunition for the evaluation required in "C". This is the path which this study will follow: define the evaluation criteria covering the economic, technical and qualitative aspects to be in a position subsequently to evaluate the performance of each system using these same criteria. The evaluation will make it possible to highlight the potential of each system in the Quebec context and to establish a comparison among all the systems.

3. THE CHOICE OF METHODOLOGY

Two options appeared as far as methodology was concerned: the **EMPIRICAL** approach based on sufficient enumeration and the **ANALYTICAL** approach based on the analysis of typical cases using criteria.

The empirical approach is the summation of the representative characteristics taken from "the largest number". This is an approach providing the researcher with much security since, in principle, it is based on numerous cases. But this approach can prove misleading in a comparative study, since the quantity of samples available will vary considerably from one system to another.

The architectural characteristics of the sample projects are also likely to be very distinct: finish materials, geometric complexity and dimensions. It is known that each of these characteristics can have a enormous influence on the cost; we know, moreover, that the unit cost is not directly proportional to the area, but that it tends to decrease as the area increases.

We have thus chosen the second option, the analytical approach, where the same criteria are used to evaluate the systems applied to the same model plans. There is insufficient enumeration, we admit this, but there will be a "comparison among comparables".

Five stages appear evident and rational:

1. **WHAT TO COMPARE, i.e., SELECTION AND THE DESCRIPTION** of pertinent systems in the context of Quebec which was the territory targetted by the study;

2. **HOW TO COMPARE, i.e., THE MODELIZATION** of the model plans compatible with the systems identified in order to allow for a comparison among comparables;

3. **THE CHOICE OF EVALUATION CRITERIA** which are representative of the economic, technical and qualitative aspects;

4. **THE RESULTS, i.e., THE TABLE OF DATA** obtained using the criteria for each of the systems; sensitivity factors will make it possible to put all the various data obtained on the same scale to facilitate the reading thereof. All this is accompanied by a brief analysis of the results.

5. **THE CONCLUSION,** i.e., an outline of the lessons to be learned.

4. THE SYSTEMS TO BE STUDIED

What systems will be compared and how are these to be selected? The question applies both to traditional building methods as well as to the manufactured and industrialized systems. This also means that each of the systems selected can be used, without any particular difficulty, to execute each of the three housing models: **SINGLE-DETACHED UNITS, ROW HOUSING and the LOW-RISE MULTI-FAMILY HOUSING.**

4.1 TRADITIONAL BUILDING METHOD

By **TRADITIONAL BUILDING METHOD** is meant those types of construction corresponding to market habits, the main characteristic of which is its high labor costs which exceed 50% of the total manufacturing cost.

Woodframe construction is the formula which is the most widespread in Quebec, both for the single family model as well as for the low-rise multi-family model.

Even if reinforced concrete and load bearing masonry are rarely used in the single family model, we judge that it is important to consider these as pertains to the low-rise multi-family model in order, among other things, to facilitate the comparison with the manufactured and industrialized systems which do use these elements.

4.2 MANUFACTURED AND INDUSTRIALIZED SYSTEMS

The **MANUFACTURED AND INDUSTRIALIZED SYSTEMS** are methods based on mass quantity production to amortize the cost of the equipment and processes necessary to simplify production. The equipment and processes are generally installed in the factory, although certain new applications may also be executed directly on site. They will be chosen so as to represent the three major categories of systems: the manufactured **MECCANO** assembled on site, the **"MANUFACTURED VOLUME"** and the **HYBRID**; as defined on the next page (#2).

4.2.1 THE MECCANO SYSTEM WITH SITE ASSEMBLY

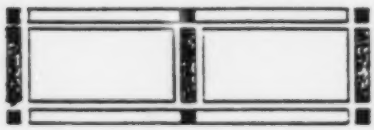
All the sub-systems, including the frame, are factory built but transported to the site to be assembled.

The investment is moderate, since the building is cut so as to make the elements relatively easy to manufacture, compact to transport and easy to divide among a certain number of sub-contractors.

But a long sequence of assembling, pointing and finish work requiring specialized manpower is still necessary on site; these operations are also exposed to climatic and geographical constraints which are peculiar to any on site work.

The four types of systems making up this category are based on the geometry of the frame sub-system:

"A"- BEAM AND COLUMN

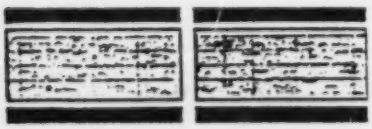


A frame which necessarily implies horizontal and vertical infill with all the subsequent operations involving pointing and airtightness.

"B"- SLAB AND POST

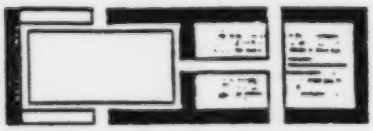
By eliminating horizontal infill, progress is made towards greatly simplicity.

"C"- PANELS



Slabs and load bearing walls distributing the loads while also assisting in sound proofing.

"D"- INTEGRATED JOINT



Monolithic element which facilitates the pointing work by locating the actual joint away from the geometric meeting point.

4.2.2 THE "MANUFACTURED VOLUME"

Use is made here of the assembly line process: **all the spaces and the elements of the dwelling are entirely manufactured, assembled and finished in the factory; as tridimensional modules, they have only to be hooked up to the fondations and to the services once they arrive on site,** so that labor costs represent only 15% to 20% of the total cost.

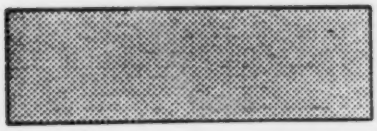
On the other hand, the modules contain much air (open space) and thus we end up transporting all this air and the installation fees are nevertheless significant. But the main disadvantage with this category of system is that it requires a high initial investment and many orders have to be guaranteed since the same factory is responsible for practically all the system: to alleviate this problem, the manufacturers will attempt to maximize the use of sub-contracting.

The "manufactured volume" concept is available in two forms:

"E"- THE SECTIONAL MODULE

A small volume which is easy to transport; but which means that it requires a supplement, to be twinned up with another module, or deployment on site.

"F"- THE BOX



A self contained unit entirely manufactured in the factory.

4.2.3 THE HYBRID CONCEPT

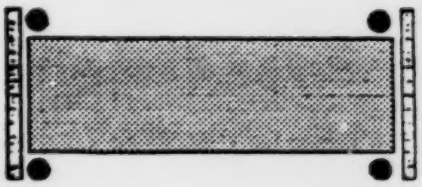
This third category is in fact the hybrid in that it attempts to combine the advantages of the first two concepts: **manufacture the sophisticated elements of the building in the factory, and allow the operations which are very difficult to execute prior to the transportation of the building, on site.**

Three formulas are possible:

"G"- LOAD BEARING CORE

The "serving" area of the building, i.e., the equipment/services core is manufactured in the factory as a volume with a structural capacity to support prefabricated slabs as well as the envelope and partition panels.

"H"- THE MEGASTRUCTURE



A frame supporting the manufactured volumes as live loads in order to make it possible to increase the height of the structure by avoiding stacking. Due to this frame redundancy, this formula is more spectacular than it is realistic.

"I"- THE SITE FACTORY

The idea is to bring on site all the equipment necessary to actually transform the site into a factory. In the case of sub-systems other than the frame, their complexity justifies the MECCANO approach.

4.3 SELECTION OF THE SYSTEMS

Four types of systems were specified in the "description of the mandate" issued by SHC and CMHC. The first three belong to the **MECCANO SITE ASSEMBLED FAMILY: the open frame panels,** the **panels with rigid insulation** and the **panels with flexible insulation.** The fourth belongs to the **MANUFACTURED VOLUME** family and these are modular factory built woodframe homes called **modular systems** in this mandate.

These four systems are based, to a great extent, on the traditional woodframe concept. Their advantage is essentially the fact that they can be prefabricated:

- Rationalization of work using an assembly line;
- Special equipment and permanent lifting apparatus (cranes);
- Semi-skilled labor;
- Climatic protection (work inside);
- Greater purchase power due to the fact that their is only one delivery point;

We include a fifth system, **permanent concrete form works** with rigid insulation both to take into account the increasing importance of this formula as well as to ensure representation of the **hybrid** concept.

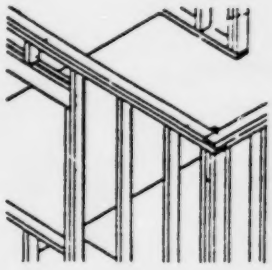
In order to give the study a temporal aspect, we shall not limit ourselves to the five systems as mentioned. We will add two solutions from the prefabricated **MECCANO** family which appear appropriate here; the **sandwich panel** as well as the **prefabricated concrete panel,** a solution which is not as widespread at the present time but it is sufficiently "classic" to deserve being in a study such as this one.

Lastly, we will also deal with two manufactured systems which are in use abroad which, in our opinion, are of interest for Quebec. We cannot ignore the **light wood frame panels assembled by automation in Sweden** and we also have to pay much attention to the manufactured **modules with structual steel edges** in Japan. In this latter case, the most industrialized systems in the world are used and, had it not been for the spectacular increase in the value of the Yen as decreed in 1985 for evident political reasons, these modules would have already invaded the Quebec market just as Japanese cars have.

5. DESCRIPTION OF THE SYSTEMS TO BE STUDIED

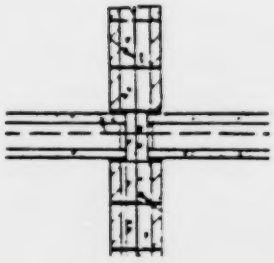
The reader will find below a brief description of the specific aspects of each system selected for the reasons listed in the preceding chapters. In Appendix "A", the reader will find an illustrated descriptive sheet containing the appropriate information for each of the following sub-systems: frame/envelope/partition/services.

5.1 TRADITIONAL CONSTRUCTION METHODS CURRENTLY IN USE IN QUEBEC



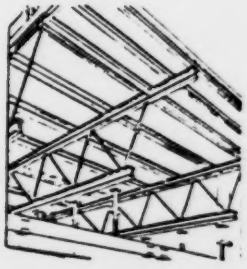
5.1.1 WOOD FRAME

Vertical frame using wood studs (2" X 4" or 2" X 6") and horizontal frame with solid joists (2" X 10") or open web/composite trusses; envelope and interior partitions of the same type, with integrated insulation and variable cladding(#3).



5.1.2 BEARING MASONRY

Frame based on standard elements: concrete blocks installed manually, steel trusses or extruded prestressed concrete slabs (#4).



5.1.3 MONOLITHIC CONCRETE CAST ON SITE

The walls are usually segments of a length sufficient to meet the purely structural requirements, cast using traditional forms in plywood or mechanized forms such as travelling forms (#6).

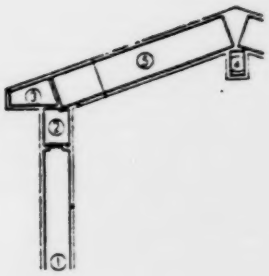
5.2 MANUFACTURED SYSTEMS CURRENTLY AVAILABLE IN QUEBEC

5.2.1 LIGHT OPEN FRAME PANELS (flexible insulation)

Pre-assemblage, at the factory, of the walls, floors and roofs of the wood-frame construction to benefit from the inherent advantages of the manufactured concept (#8).

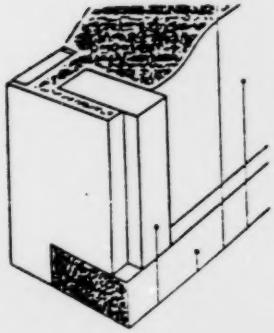
5.2.2 STRESSED SKIN BOX PANELS

Factory production of stressed skin box panels using wafer boards, saves on materials, integration of insulation/wiring and simplification of assemblage on site; finish work to be completed in the traditional manner (#9).



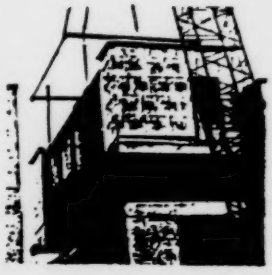
5.2.3 COMPOSITE PANELS WITH RIGID INSULATION

Use of extruded polystyrene panels as a permanent frame to assemble the wood studs and as a thermal break. These vertical panels are usually completed with slabs of the same type or with open web trusses with plywood apron. Finish is completed in the traditional manner (#10).



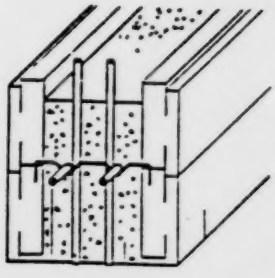
5.2.4 MODULAR FACTORY BUILT HOMES

The only approach which is entirely factory built in Quebec at the present time. Tridimensional woodframe modules assembled and finished in the factory. In the typical factory the principle of the assembly line is adapted, fueled perpendicularly by a pre-assembled components. The joint work and painting is done on site, once the module is installed.

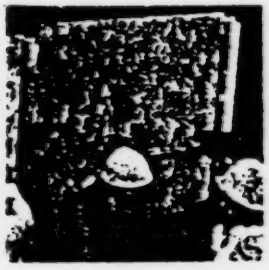


5.2.5 PERMANENT FORM WORKS USING RIGID INSULATION

Simplification of the operations involved in concrete cast on site using hollowed-out polystyrene magablocks which may be easily tongue and grooved as permanent forms (#12). Variable horizontal frame.

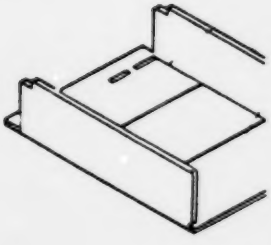


5.3 MANUFACTURING SYSTEMS LIKELY TO BECOME AVAILABLE IN QUEBEC



5.3.1 SANDWICH PANELS

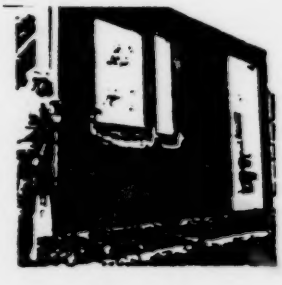
Bearing panels with a core of rigid insulation injected under pressure between the two faces of the wall; the nature of the faces can vary; tongue and grooved joint between the panels (#7).



5.3.2 PREFABRICATED CONCRETE PANELS

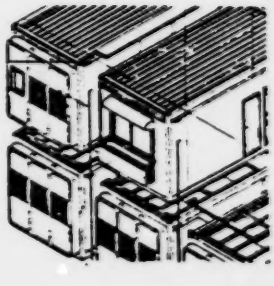
The prefabricated slabs and composite steel-concrete floor make it possible to have spans of up to 6 to 8 meters, enough for one complete unit between two walls, and to bring the joint-area ratio within profitable limits (#14).

5.4 MANUFACTURED SYSTEMS USED ABROAD AND OF INTEREST TO QUEBEC



5.4.1 LIGHT WOODFRAME PANELS ASSEMBLED BY AUTOMATION

The Swedish panel systems manufactured by automation and entirely finished at the factory (#15) are among the most sophisticated solutions in the world.



5.4.2 MANUFACTURED MODULES WITH STRUCTURAL STEEL EDGES, i.e., modules with para-container dimensions, which can open in 6 directions

Modules which are factory built and with structural steel edges making it possible to create one large room (#16). The highest degree of industrialization in the world.

6. MODELIZATION

In order to "compare the comparables", we shall establish a basic **architectural model which will be used as a COMMON DENOMINATOR** for the systems selected.

The architectural model is made up of three series of plans corresponding to the major spans possible for the frames of the systems studied. Each series presents a specific plan for each of the three types of dwellings (single-detached units, row-housing, low-rise multi-family housing). The table on page 15 indicates the compatibility between the plans and the systems selected: it will be noted that several systems may be compatible in two series.

6.1 DEFINITION OF THE THREE TYPES OF DWELLINGS FOR OUR STUDY

i **SINGLE DETACHED UNIT,** is a single detached house commonly called "bungalow" in its one storey model.

ii **ROW-HOUSING,** is housing which shares party walls and cross walls and which is designated as row-houses in Europe and town-houses in America; for the purposes of this study, we assume the row of four (4) houses, thus excluding the "semi-detached" formula which is made up of two houses sharing one party-wall.

iii **LOW-RISE MULTI-FAMILY HOUSING,** is a multi-family walk-up three storey building without a hallway; for the purposes of the study we shall consider four (4) units per storey (three of which are distinct types) for a total of twelve (12) units.

6.2 DEFINITION OF THE THREE SERIES OF PLANS MAKING UP THE ARCHITECTURAL MODEL

SERIES "A"
Large spans (6 to 7 meters) corresponding mainly to solutions incorporating the panels, with the composite trusses making it possible to attain the same performance as pre-stressed or monolithic concrete.

- Single Detached:	100.60 m2
- Single Family Row:	125.00 m2
- Low-Rise Multi-Family:	
i - small two bedroom	91.08 m2
ii - large two bedroom	99.36 m2
iii - large three bedroom	134.64 m2

SERIES "B"
Small transversal spans for the tridimensional solutions, limited by the road clearance (maximum 4.85 m).

- Single Detached:	100.50 m2
- Single Family Row:	130.56 m2
- Low-Rise Multi-Family:	
i - small two-bedroom	92.88 m2
ii - large two-bedroom	100.62 m2
iii - large three-bedroom	134.10 m2

SERIES "C"
Small transversal spans for the steel frame modules applicable solely to the single detached and row-housing models (maximum 2.60 m).

- Single Detached and Row-Housing:	125.00 m2
- Low-Rise Multi-Family:	N/A

In Appendix "B", the reader will find an outline of each of these plans as well as their summary specification.

All of the plans meet the following functional criteria:

- **Simple and Modular Architecture.**

- **Neutral Entrance Way,** i.e., ability to access each of the areas within the unit without having to cross another one.

- Distinction between the **"served area"** (leisure time) and the **"serving area"** (entrance, kitchen, bathrooms, laundry rooms, utility room, etc...).

- **Autonomy** of the three sectors of the **"served zone"** (social/family/individual).

- **Double Orientation** (transversal plan or in a corner) to obtain
  - Natural ventilation
  - Continual daily sunlight
  - Maximum visual field.

- **Optimization of the Facade** using the critical dimensions to maximize density, even if it is necessary to transfer to the center of the unit the storage spaces and a good part of the "serving" zone.

  The vertical bearing elements corresponded to the **private/semi-private boundaries** so as to optimize soundproofing and fire protection.

- The **stairways** are located so as not to hinder the operation of the doors.

- **The private exterior leisure area** has a minimal dimension of 2.0 m in order to be able to eat outside and/or set up lawn chairs.

6.3 TABLE OF COMPATIBILITY AMONG THE PLANS AND SYSTEMS

	SINGLE DETACHED			ROW HOUSING			LOW RISE LIGHT MATERIAL		FAMILY HOUSING	
	A	B	C	A	B	C	A		B	
1.1 WOODFRAME	●	O		●	O		●		O	
1.2 BEARING MASONRY				●			●		O	
1.3 MONOLITHIC CONCRETE CAST ON SITE				●	O		●		O	
2.1 LIGHT PANEL OPEN FRAMING	●	O		●	O		●		O	
2.2 STRESSED SKIN BOX PANELS	O	●			●					
2.3 COMPOSITE PANELS WITH RIGID INSULATION	●	O		●	O		●		O	
2.4 MODULAR HOMES	O	●			●				●	
2.5 PERMANENT FORM WORKS USING RIGID INSULATION	●	O		●	O		●		O	
3.1 SANDWICH PANELS	●	O		●	O					
3.2 PREFABRICATED CONCRETE PANELS				●	O		●		O	
4.1 LIGHT WOOD FRAME PANELS ASSEMBLED BY AUTOMATION	●	O		●	O		●		O	
4.2 MANUFACTURED MODULES WITH STRUCTURAL STEEL EDGES			●			●				

Caption:

O compatibility

● plan chosen for economic evaluation

The table shows compatibility among the plans in the three series which make up the architectural module and the systems chosen.

It should be pointed out that each plan is studied to use a C.A.D. (Computer Assisted Design) software so that it can be modified systematically to adjust to the particular characteristics of each of the building systems to be evaluated; thus, it was possible to respect the nature of said system while getting closer to the typical case used for cost analysis.

7. EVALUTION CRITERIA

The comparative evaluation involves the economic, technical and qualitative aspects. The economic evaluation is based exclusively on the unit construction cost per square metre; the cost was determined using the typical plans described in the preceding chapter. The technical evaluation involves the system itself as the qualitative evaluation applies to the building produced by the system.

In view of "comparing comparables", more precisely to measure, on a common scale, the numerical values corresponding to the various criteria, we adopted a "SENSITIVITY CURVE" method as pertains to the technical and qualitative aspects.

This involves developing a specific curve to correspond to the numerical values of the criteria on an axis and to make them measurable using a common scale on the other axis. The choice of the range of values extenting from 1 to 5 makes it possible to spead out the variables to be able to distinguish between them as clearly as possible.

The fact of producting results on a common scale make it possible to compare them and even to add them together, although it is however necessary to adapt weighting factors in this case to respect the relative importance of the various criteria.

7.1 ECONOMIC CRITERIA

The economic evaluation is based exclusively on the unit construction cost per square meter.

The construction cost includes the profit and the fees charged by the manufacturers, the sub-contractors and the general contractor.

For the purposes of this study, in order to obtain a comparison, the unit cost is based exclusively on the construction of one unit. In the case of the row-housing, the unit cost is calculated for only one unit based on 25% of the cost applicable to a row of four. The costs are determined according to an average in the construction industry for the Montreal region and for the large cities in the suburbs.

The fact of producing in greater quantity, and this applies both to the traditional as well as to the factory built system, means an increase in productivity, however, and in labor performance and a better amortization of the equipment costs. Moreover, the project manager has greater negotiating powers. **Consequently, construction costs may be reduced by approximately 10% if one considers housing starts for a group of 10 units and more at once, regardless of the method used. According to our experience, the contractor, using this production scale, can make savings in this range, both by building in the traditional manner as well as by negotiating price reductions from the producers of factory built systems. Thus this factor does not appear to us as discriminating, in comparison terms, in the general conditions in Quebec.** It is understood, moreover, that the products generated by the factory built systems require a minimum annual production volume, but this condition is deemed to be acquired and reflected in the basic unit price.

Moreover, outside the major urban centres, greater savings could be made by using tradesmen-sub-contractors, except for the more complete factory built systems (modular houses and others).

The economic situation for the construction industry is also a factor which has a very significant impact on the cost of materials and labor. The costs which are presented in this study represent the construction market situation in 1990.

The economic evaluation does not take into consideration the cost of acquiring the land and the infrastructures nor the cost of landscaping (leveling and paving). These costs may vary substantially and are not pertinent to the study.

The plans used for the **ECONOMIC EVALUATION** do not include any architectural complexity so as not to prejudice any of the various systems studied.

An increase in the complexity of the structure would produce expensive overruns in certain systems. Moreover, this could be to the advantage of the traditional construction system since the "complexity" factor would have less impact on it.

Moreover, it was virtually impossible to establish the impact of the Goods and Services Tax, in particular for the traditional sector. To this effect, the GST is not included in the calculation of the unit cost in this study; it would seem that it has very little influence in the comparison between the various systems.

Calculating the costs involves an operation which varies depending on the very nature of each of the four categories of technology description in chapter 4; it is considered that the elements not provided by the systems are obtained through readily available solutions based on traditional construction.

The sources of information on the costs are:

1- For the traditional construction methods currently used in Quebec: UNIT PRICES by component category.

2- For the manufactured systems currently available in Quebec: prices based mainly on the projects by builders having already used said systems; prices obtained from the builders themselves, from suppliers and/or manufacturers depending on the case.

3- For manufactured systems likely to become available in Quebec: interview with the developers and collection of data on previous projects or prototypes (or based on estimates); these data are adjusted, as needed, with the assistance of data provided by comparable systems.

4- For systems used abroad: evaluated based on published data or on submissions to Canadian or Quebec promoters.

The reader should note that the difference between the sources of information from one category to another may produce a varying level of accuracy and reliability; in spite of the measures taken to resolve this problem. (See Appendix "C").

N.B. The identity of the sources is disclosed under the heading "REFERENCES" and "CREDITS" in Appendix "D".

7.2 TECHNICAL CRITERIA ("a" to "c")

Four factors make it possible to distinguish between the scope of the systems studied, factors which become our technical evaluation criteria in this study: the magnitude of the system, the extent of industrialization and the duration of the work.

a) THE MAGNITUDE OF THE SYSTEM

The magnitude criteria is designed to define the proportion of the building covered by the system and is reflected first of all by the number of sub-systems involved.

In housing, a construction system can include up to six (6) sub-systems namely:

- The **FRAME**, i.e., the structure of the building;
- The **ENVELOPE**, i.e., the perimeter of the environment controlled by the building (exterior walls/doors and windows/ roof/ soffits);
- **PARTITIONING**, i.e., the sub-divisions of the buildings interior space;
- The **SERVICES**, i.e., the plumbing/heating/electrical/electronic systems and the traffic systems (stairways and elevators);
- The **EQUIPMENT**, i.e., the installations which are specific to housing such as the kitchen, bathrooms, laundry rooms, etc...
- The **FINISH WORK**, i.e., the cladding/caulking/painting/etc...

Since any one system involves the presence of at least one sub-system, we assume that each of the additional sub-systems can be classed on a 1 to 5 pointing system; the fractions representing incomplete sub-systems are added together to form one or more units.

b) THE EXTENT OF INDUSTRIALISATION

With the nature of industrialisation being to **quantatively justify a process which is capable in turn of simplifying the production of complex objects**, we can measure the extent of industrialisation according to the level of simplification in the system in relation to manual construction.

Five (5) degrees of industrialisation are generally recognized in the area of construction systems; we have listed these five below in a hierarchical order corresponding to the points granted (#2).

1- **PREFABRICATION,** i.e., a procedure similar to traditional construction but with manufacturing executed in the factory;

2- **MECHANISATION,** i.e., recourse to mechanized equipment to reduce the workload of the laborer;

3- **AUTOMATION,** i.e., the tool completely replaces the laborer;

4- **ROBOTISATION,** i.e., the same tool executes many diversified tasks;

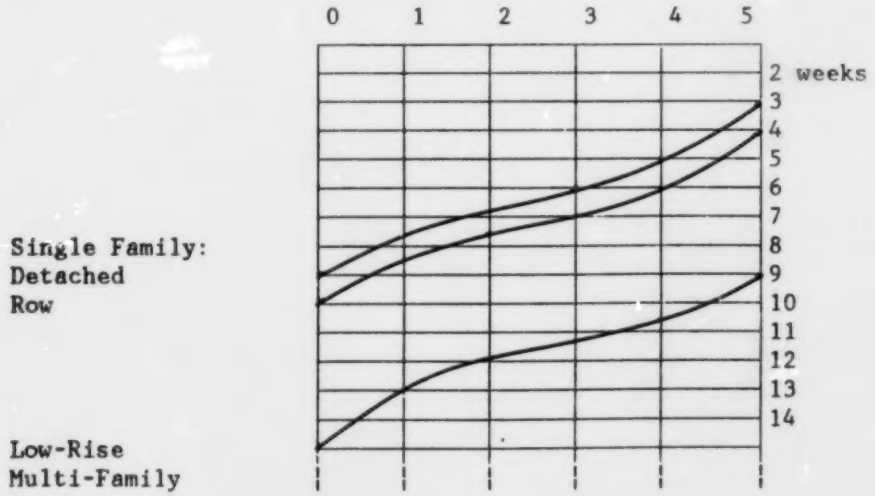
5- **REPRODUCTION,** i.e., innovative technology capable of reducing a number of operations involved in the production of each unit.

The evaluation is normally conducted at the sub-system level and the fractions representing partial satisfaction of a degree of industrialisation may be added together to total one or more units.

c) **DURATION OF THE WORK**

In addition to representing advantages and disadvantages on an operational level, particularly due to climatic variables, the duration of the work will also condition interim financing for the project and will thus have a direct influence on the total construction cost.

Here we measure the total duration of the site work (including the operations which are not attributable to the system as such) and we use a sensitivity curve to illustrate, in a significant manner, the "duration of the work" (going from 3 to 15 weeks) on a scale of 1 to 5.



7.3 QUALITATIVE CRITERIA ("d" to "e")

The study will also take into account the qualitative impact of the systems of the buildings which they produce. For this purpose, the following two (2) criteria appear to us to be both pertinent and objectively measurable: architectural flexibility and quality of the joint work.

d) ARCHITECTURAL FLEXIBILITY

This criteria is designed to reflect the system's capacity to allow for diversified planning and to adapt to changes during occupancy.

Each of the following characteristics is worth one (1) point on the "1 to 5" scale:

- diversity of width during planning, as a multiple of 30 cm;
- diversity of length during planning, as a multiple of 30 cm;
- diversity of height during planning, as a multiple of 10 cm;
- possibility of modifying two parallel partitions in the same room, during use;
- possibility of growth by linking up two adjacent units, during use.

e) QUALITY OF THE JOINT WORK

A system is no better than its joints. We will express the quality of the joint work using a point system, based on a study, involving one (1) point for each of the following aspects:

- ingenuity;
- simplicity;
- accuracy;
- sturdiness;
- continuity of thermal break.

8. THE RESULTS

The reader will find, on the following pages, a series of tables showing the results of the evaluation of the systems selected for each of the three dwellings studied.

The first series provides a breakdown of the economic data.

The second series presents a synthesis of the results: the economic results are expressed using the unit construction cost; the results for the technical and qualitative criteria are obtained based on a point system using basically a "1 to 5" scale. In Appendix "A", you will find an explanatory evaluation sheet for the results of each system.

A brief analysis of the results completes the study.

8.1 ECONOMIC DATA TABLES FOR EACH OF THE THREE DWELLINGS STUDIED

8.1.1 SINGLE DETACHED MODEL

ECONOMIC EVALUATION
Single Detached Model
100m2

S: Cost Included in the System
*: Differential Cost of the System

PLAN A or B	TRADITIONAL WOOD	OPEN WEB PANELS	STRESSED SKIN BOX PANELS	RIGID INS. PANELS	MODULAR HOMES	PERMANENT FORMWORKS
COST OF SYSTEM		$23 000	$25 000	$ 3 050	$45 000	$23 500
CONSTRUCTION COSTS						
Excavation Infill	$ 2 900	$ 2 900	$ 2 900	$ 2 900	$ 2 900	$ 2 900
Formwork	$ 2 550	$ 2 550	$ 2 550	$ 2 550	$ 2 550	$ S
Concrete	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ S
Concrete Pump	$ 500	$ 500	$ 500	$ 500	$ 500	$ S
Reinforcing Steel	$ 300	$ 300	$ 300	$ 300	$ 300	$ S
Tar	$ 150	$ 150	$ 150	$ 150	$ 150	$ S
Slab Finish Work	$ 450	$ 450	$ 450	$ 450	$ 450	$ S
Parging	$ 350	$ 350	$ 350	$ 350	$ 350	$ S
Materials (wood, insulation, etc.)	$ 9 000	S	* $ 500	* $ 6 920	S	* $ 1 100
Gross Carpentry	$ 8 500	S	* $ 400	$ 8 500	* $ 700	* $ 900
Roof Trusses	$ 2 050	S	S	$ 2 050	S	$ 2 050
Roofer (shingles)	$ 1 600	S	S	$ 1 600	S	$ 1 600
Plumbing	$ 4 500	$ 4 500	$ 4 500	$ 4 500	* $ 1 600	$ 4 500
Electricity	$ 3 500	$ 3 500	$ 3 500	$ 3 500	* 400	$ 3 500
Drywall (installation & material)	$ 4 500	$ 4 500	* $ 7 000	$ 4 500	* $ 1 400	* $ 7 000
Windows, Exterior Doors	$ 4 500	S	$ 4 500	$ 4 500	S	$ 4 500
Masonry	$ 1 400	$ 1 400	$ 1 400	$ 1 400	$ 1 400	$ 1 400
Aluminium	$ 3 000	$ 3 000	$ 3 000	$ 3 000	S	$ 3 000
Ceramic	$ 1 000	$ 1 000	$ 1 000	$ 1 000	S	$ 1 000
Wood Trim	$ 2 000	$ 2 000	$ 2 000	$ 2 000	S	$ 2 000
Stairs and Handrails	$ 1 100	$ 1 100	$ 1 100	$ 1 100	S	$ 1 100
Cupboards	$ 3 500	$ 3 500	$ 3 500	$ 3 500	S	$ 3 500
Finish Carpentry	$ 1 000	$ 1 000	$ 1 000	$ 1 000	S	$ 1 000
Painting	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ 1 200
Carpets	$ 3 200	$ 3 200	$ 3 200	$ 3 200	$ 3 200	$ 3 200
Fixtures	$ 500	$ 500	$ 500	$ 500	S	$ 500
Mirror	$ 300	$ 300	$ 300	$ 300	S	$ 300
Prewiring (tel. cable)	$ 150	$ 150	$ 150	$ 150	S	$ 150
Cleaning	$ 150	$ 150	$ 150	$ 150	150	$ 150
Overhead	$ 7 000	$ 5 000	$ 7 000	$ 7 000	* $ 3 000	$ 6 000
TOTAL	$74 850	$70 200	$82 100	$75 820	$69 250	$76 050
COST per sq. M 2	$ 749	$ 702	$ 821	$ 758	$ 693	$ 761

8.1.2 ROW HOUSING MODEL

ECONOMIC EVALUATION
Row Housing
130m2

S: Cost Included in the System
*: Differential Cost of the System

PLAN A or B	TRADITIONAL WOOD	BEARING MASONRY	CONCRETE CAST ON SITE	OPEN WEB PANELS	STRESSED SKIN BOX PANELS	RIGID INS. PANELS	MODULAR HOMES	PERMANENT FORMWORKS	PREFAB CONCRETE PANELS
COST OF SYSTEM		$ 18 500		$ 24 500	$ 30 560	$ 5 880	$ 70 000	$ 27 800	$ 35 200
CONSTRUCTION COSTS									
Excavation Infill	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000
Formwork	$ 2 200	$ 2 200	* $ 11 250	$ 2 200	$ 2 200	$ 2 200	$ 2 200	$ S	$ 2 200
Concrete	$ 3 000	$ 3 000	* $ 5 500	$ 3 000	$ 3 000	$ 3 000	$ 3 000	$ S	$ 3 000
Concrete Pump	$ 500	$ 500	* $ 2 000	$ 500	$ 500	$ 500	$ 500	$ S	$ 500
Reinforcing Steel	$ 200	$ 200	* $ 5 000	$ 200	$ 200	$ 200	$ 200	$ S	$ 200
Tar	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150	$ S	$ 150
Slab Finish Work	$ 375	$ 375	$ 375	$ 375	$ 375	$ 375	$ 375	$ S	$ 375
Parging	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ 200	$ S	$ 200
Materials (wood, insulation, etc.)	$ 9 000	* $ 1 000	* $ 1 000	$ S	* $ 400	* $ 5 100	$ S	* $ 800	* $ 1 000
Gross Carpentry	$ 10 000	* $ 1 500	* $ 1 500	$ S	* $ 600	$ 10 000	* $ 800	* $ 600	* $ 1 500
Roof Trusses	$ 1 600	$ 1 600	$ 1 600	$ S	$ S	$ 1 600	$ S	$ 1 600	$ 1 600
Roofer (shingles)	$ 900	$ 900	$ 900	$ S	$ S	$ 900	$ S	$ 900	$ 900
Plumbing	$ 5 000	$ 5 000	$ 5 000	$ 5 000	$ 5 000	$ 5 000	* $ 2 000	$ 5 000	$ 5 000
Electricity	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	* $ 500	$ 4 000	$ 4 000
Drywall (installation & material)	$ 5 250	* $ 14 800	* $ 14 800	$ 5 250	* $ 10 000	$ 5 250	* $ 2 000	* $ 8 000	* $ 10 500
Windows, Exterior Doors	$ 5 500	$ 5 500	$ 5 500	$ S	$ 5 500	$ 5 500	$ S	$ 5 500	$ 5 500
Masonry	$ 5 750	$ 5 750	$ 5 750	$ 5 750	$ 5 750	$ 5 750	$ 5 750	$ 5 750	$ 5 750
Aluminium	$ 850	$ 850	$ 850	$ 850	$ 850	$ 850	$ S	$ 850	$ 850
Ceramic	$ 1 300	$ 1 300	$ 1 300	$ 1 300	$ 1 300	$ 1 300	$ S	$ 1 300	$ 1 300
Wood Trim	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ 2 000	$ S	$ 2 000	$ 2 000
Stairs and Handrails	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ S	$ 1 600	$ 1 600
Cupboards	$ 3 500	$ 3 500	$ 3 500	$ 3 500	$ 3 500	$ 3 500	$ S	$ 3 500	$ 3 500
Finish Carpentry	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ S	$ 1 200	$ 1 200
Painting	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600	$ 1 600
Carpets	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000	$ 4 000
Fixtures	$ 500	$ 500	$ 500	$ 500	$ 500	$ 500	$ S	$ 500	$ 500
Mirror	$ 300	$ 300	$ 300	$ 300	$ 300	$ 300	$ S	$ 300	$ 300
Prewiring (tel. cable)	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150	$ S	$ 150	$ 150
Cleaning	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150	$ 150
Overhead	$ 7 500	$ 7 500	$ 7 500	$ 6 000	$ 7 500	$ 7 500	* $ 3 000	$ 6 000	$ 7 500
TOTAL	$ 80 275	$ 91 825	$ 91 175	$ 76 275	$ 95 085	$ 82 255	$ 98 425	$ 85 100	$ 104 225
COST per sq. M 2	$ 618	$ 706	$ 701	$ 587	$ 731	$ 633	$ 757	$ 655	$ 802

8.1.3 LOW-RISE MULTI-FAMILY MODEL

ECONOMIC EVALUATION
12 Unit Multi-Family Building
3 Storeys Above Grade
1250m2

S: Cost Included in the System
*: Differential Cost of the System

PLAN A or B	TRADITIONAL WOOD	BEARING MASONRY	CONCRETE CAST ON SITE	OPEN WEB PANELS	RIGID INS. PANELS	MODULAR HOMES	PERMANENT FORMWORKS	PREFAB CONCRETE PANELS
COST OF SYSTEM		$182 550		$220 000	$ 39 200	$590 000	$284 000	$273 900
CONSTRUCTION COSTS								
Excavation Infill	$ 16 000	$ 16 000	$ 16 000	$ 16 000	$ 16 000	$ 16 000	$ 16 000	$ 16 000
Formwork	$ 12 000	$ 12 000	* $ 87 500	$ 12 000	$ 12 000	$ 12 000	$ S	$ 12 000
Concrete	$ 19 550	$ 19 550	* $ 52 000	$ 19 550	$ 19 550	$ 19 550	$ S	$ 19 550
Concrete Pump	$ 1 150	$ 1 150	* $ 7 500	$ 1 150	$ 1 150	$ 1 150	$ S	$ 1 150
Reinforcing Steel	$ 3 000	$ 3 000	* $ 32 500	$ 3 000	$ 3 000	$ 3 000	$ S	$ 3 000
Tar	$ 500	$ 500	$ 500	$ 500	$ 500	$ 500	$ S	$ 500
Slab Finish Work	$ 2 250	$ 2 250	* $ 10 500	$ 2 250	$ 2 250	$ 2 250	$ S	$ 2 250
Materials (wood, insulation, etc.)	$110 000	* $ 9 000	$ 9 000	$ S	* $ 83 400	$ S	* $ 9 000	$ S
Gross Carpentry	$ 64 000	* $ 10 000	$ 10 000	$ S	$ 64 000	$ S	* $ 10 000	$ S
Roof Trusses	$ 15 500	$ 15 500	$ 15 500	$ S	$ 15 500	$ S	$ 15 500	$ S
Roofer (shingles)	$ 3 200	$ 3 200	$ 3 200	$ S	$ 3 200	$ S	$ 3 200	$ S
Plumbing	$ 41 000	$ 41 000	$ 41 000	$ 41 000	$ 41 000	* $ 20 000	$ 41 000	$ 41 000
Electricity	$ 36 000	$ 36 000	$ 36 000	$ 36 000	$ 36 000	* $ 6 000	$ 36 000	$ 36 000
Drywall (installation & material)	$ 39 000	* $ 98 000	* $ 98 000	$ 39 000	$ 39 000	* $ 15 000	* $ 65 000	* $ 71 500
Windows, Exterior Doors	$ 29 500	$ 29 500	$ 29 500	$ S	$ 29 500	$ S	* $ 27 500	$ 29 500
Masonry	$ 48 000	$ 48 000	$ 48 000	$ 48 000	$ 48 000	$ 48 000	$ 48 000	$ 48 000
Aluminium	$ 12 000	$ 12 000	$ 12 000	$ 12 000	$ 12 000	$ S	$ 12 000	$ 12 000
Ceramic	$ 13 500	$ 13 500	$ 13 500	$ 13 500	$ 13 500	$ S	$ 13 500	$ 13 500
Wood Trim	$ 13 800	$ 13 800	$ 13 800	$ 13 800	$ 13 800	$ S	$ 13 800	$ 13 800
Stairs and Handrails	$ 31 000	$ 31 000	$ 31 000	$ 31 000	$ 31 000	$ S	$ S	$ 31 000
Cupboards	$ 26 400	$ 26 400	$ 26 400	$ 26 400	$ 26 400	$ S	$ 26 400	$ 26 400
Finish Carpentry	$ 11 500	$ 11 500	$ 11 500	$ 11 500	$ 11 500	$ S	$ 11 500	$ 11 500
Painting	$ 12 000	$ 12 000	$ 12 000	$ 12 000	$ 12 000	$ 12 000	$ 12 000	$ 12 000
Carpets	$ 22 000	$ 22 000	$ 22 000	$ 22 000	$ 22 000	$ 22 000	$ 22 000	$ 22 000
Fixtures	$ 8 000	$ 8 000	$ 8 000	$ 8 000	$ 8 000	$ S	$ 8 000	$ 8 000
Mirror	$ 1 500	$ 1 500	$ 1 500	$ 1 500	$ 1 500	$ S	$ 1 500	$ 1 500
Prewiring (tel. cable)	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ 1 200	$ S	$ 1 200	$ 1 200
Cleaning	$ 1 000	$ 1 000	$ 1 000	$ 1 000	$ 1 000	$ 1 000	$ 1 000	$ 1 000
Basement Finish	$ 24 000	$ 24 000	$ 24 000	$ 24 000	$ 24 000	$ 24 000	$ 24 000	$ 24 000
Overhead	$ 52 000	$ 52 000	$ 52 000	$ 42 000	$ 52 000	* $ 20 000	* $ 38 000	$ 52 000
TOTAL	$670 550	$757 100	$726 600	$658 350	$683 150	$812 450	$740 100	$784 250
COST per sq. M 2	$ 536	$ 606	$ 581	$ 527	$ 547	$ 650	$ 592	$ 627

8.2. SYNTHESIS TABLE AND BRIEF ANALYSIS OF RESULTS

8.2.1 SINGLE DETACHED UNITS

	COST	a- MAGNITUDE OF THE SYSTEM	b- EXTENT OF INDUSTRIALI-ZATION	c- DURATION OF WORK	d- ARCHITECTURAL FLEXIBILITY	e- QUALITY OF JOINT WORK
1.1 WODDFRAME	749	5	0	0	5	2
2.1 OPEN WEB PANELS	702	2	1	1	5	2
2.2 STRESSED SKIN BOX PANELS	821	3	2	3	3	4
2.3 COMPOSITE PANELS WITH RIGID INS.	758	1	2	0	5	3
2.4 MODULAR HOUSES	693	5	2	4	3	3
2.5 PERMANENT FORMWORKS	761	2	2	0	3	5
3.1 SANDWICH PANELS	749	2	2	1	3	5
4.1 LIGHT PANELS USING AUTOMATION	757	3	3	4	5	5
4.2 MODULES WITH STRUCTURAL STEEL EDGES	955	5	4	5	4	4

BRIEF ANALYSIS OF THE RESULTS FOR THE SINGLE DETACHED MODEL

One system distinguishes itself in the **SINGLE DETACHED UNIT** category and that is the **FACTORY BUILT MODULAR HOME**. Not only does the latter represent the most economical solution, but it is also the best system as pertains to technical and qualitative criteria.

The investment required in equipment may seem high to begin with, but it must not be overlooked that the quantity of houses produced means that the impact of the cost of each house is reduced in accordance with the very definition of industrialization. Indeed it is this very equipment which makes it possible for factory built houses to take first place in Quebec, in spite of a context where demand is far below the production capacity: certain factories are currently operating at 40% or 50% of their maximum capacity on a "one shift" basis.

The same thing can be said about the **OPEN FRAME PANELS SYSTEM** as pertains to cost. This system uses precisely the same principles and materials as traditional construction, except for the fact that it makes use of labourers in the factory and is thus less expensive, and takes advantage of the benefits of prefabrication which we will point out in 4.2; the fact of being able to close the exterior envelope in under two days also reduces the site expenses.

An additional cost of approximately 10% characterizes the following group, made up of five systems three of which are variations of the woodframe system: the traditional **WOODFRAME** system itself, **LIGHT WOODFRAME** (Swedish) panels **ASSEMBLED BY AUTOMATION** and the **COMPOSITE PANELS WITH RIGID INSULATION**. On the other hand, the Swedish panels offer quality far superior to the others.

The other two systems are innovative and promising: the sandwich panels and the permanent formworks. The **SANDWICH PANEL** is noteworthy due to the process used which is similar to that defined as "reproduction" and its joints are both very ingenious and efficient.

The **PERMANENT FORMWORKS** system provides a hybrid solution using a kit of metal and plastic fastening devices and polystyrene mega-blocs; this whole system can be easily set-up on site and makes it possible to cast a monolithic concrete frame which, in addition to its intrinsic qualities, posts a superior thermal performance and easily compensates for the difference in cost.

One has to avoid drawing conclusions concerning the cost of the Japanese manufactured **MODULES WITH STRUCTUAL STEEL EDGES**: a return to the exchange rate prior to 1985 would probably make it possible for the system to outclass all the other systems both on the economic as well as the qualitative level.

8.2.2 ROW HOUSING

	COST	a- MAGNITUDE OF THE SYSTEM	b- EXTENT OF INDUSTRIALI-ZATION	c- DURATION OF WORK	d- ARCHITECTURAL FLEXIBILITY	e- QUALITY OF JOINT WORK
1.1 WODDFRAME	618	5	0	1	4	2
1.2 BEARING MASONRY	706	2	1	0	3	3
1.3 CONCRETE CAST ON SITE	701	1	1	0	3	2
2.1 OPEN WEB PANELS	587	2	1	4	4	2
2.2 STRESSED SKIN BOX PANELS	731	3	2	3	3	4
2.3 COMPOSITE PANELS WITH RIGID INS.	633	1	2	1	4	3
2.4 MODULAR HOUSES	757	5	2	5	3	3
2.5 PERMANENT FORMWORKS	655	2	2	0	3	5
3.1 SANDWICH PANELS	618	2	2	4	3	5
3.2 PREFAB CONCRETE PANELS	802	2	2	3	3	3
4.1 LIGHT PANELS USING AUTOMATION	719	3	3	5	4	5
4.2 MODULES WITH STRUCTURAL STEEL EDGES	1050	5	4	5	3	4

BRIEF ANALYSIS OF THE RESULTS FOR THE ROW HOUSING MODEL

The **ROW HOUSING** evaluation presents us with an ambiguous situation. The **OPEN FRAME PANEL** system clearly outclasses all the other systems on an economic level, followed closely (+8%) by the traditional **WOODFRAME** and the **SAN :ICH PANELS.** The **COMPOSITE PANELS WITH RIGID INSULATION** and the **PERMANENT FORMWORKS** are found a little further back with a spread of +2 to +5%.

It is not the result of chance that three out of the five solutions based on the woodframe system end up in the same cost category: whereas the traditional system requires very little equipment, the investment required for prefabricated panels uses the labor cost which was saved on site. In all the cases, we are dealing with the same materials, and comparable or similar assemblage methods. In other words, the fact of prefabricating a "para-traditional" wood panel in factories (i.e., which is similar to traditional construction) does not produce any significant difference: this is only logical and the comparisons established below confirms this.

The two other solutions make innovative uses of rigid insulation: as a structual core in the case of sandwich panels and as forms in the case of permanent formworks.

The fact is that the quality of the permanent formworks, based on the criteria, is clearly superior, if only for the monolithic concrete walls and the fire protection and thermal insulation performance provided. This is an ingenious system, operating directly on site using industrialized components provided by sub-contractors (thus minimal investment).

The **MODULAR HOMES** certainly score worse here due to the requirement for a crane to pile the modules, to the double ceiling-floor situation and to the fact that it is necessary to transport and to connect the four modules together on site.

The warning given concerning the manufactured modules with structual steel edges for the single detached model also applies to the row housing model.

8.2.3 LOW RISE MULTI-FAMILY HOUSING

	COST	a- MAGNITUDE OF THE SYSTEM	b- EXTENT OF INDUSTRIALI-ZATION	c- DURATION OF WORK	d- ARCHITECTURAL FLEXIBILITY	e- QUALITY OF JOINT WORK
1.1 WODDFRAME	536	5	0	2	5	2
1.2 BEARING MASONRY	606	2	1	0	3	3
1.3 CONCRETE CAST ON SITE	581	1	1	0	3	2
2.1 OPEN WEB PANELS	527	2	1	5	5	2
2.3 COMPOSITE PANELS WITH RIGID INS.	547	1	2	2	5	3
2.4 MODULAR HOUSES	650	5	2	5	3	3
2.5 PERMANENT FORMWORKS	592	2	2	0	3	5
3.2 PREFAB CONCRETE PANELS	627	2	2	3	3	3
4.1 LIGHT PANELS USING AUTOMATION	684	3	3	5	5	5

BRIEF ANALYSIS OF THE RESULTS FOR THE LOW-RISE MULTI-FAMILY MODEL

As for the **LOW-RISE MULTI-FAMILY HOUSING MODEL,** the system is similar to that for the row housing model: as pertains to cost, the traditional method and its prefabricated offsprings end up in first place. Not by far however (+6 to +13%), since the **REINFORCED CONCRETE, BEARING MASONRY** and **PERMANENT FORMWORKS** with clearly more evident fire protection and soundproofing characteristics, advantages which can easily justify a higher sales price, also end up in a good position.

PREFABRICATED CONCRETE PANELS are more expensive, for the reasons outlined above; however, the speed with which they can be installed on site makes it possible to put lots which are usually very expensive in a profit making position due to the population density which is sought, and this may reduce the total cost of the project accordingly.

Selling at $123.00 per sq. metre more than open woodframe panels, the **MODULAR HOMES** are too expensive; on the other hand, their degree of soundproofing is clearly superior since each box has its own envelope.

9. CONCLUSION

It is not surprising to see the traditional system as well as the prefabricated system based on the traditional system end up in first place in two cases out of three as pertains to cost, but it is important to understand that the industrialized solutions of the **MANUFACTURED VOLUME VARIETY** (the modular homes) and the **"HYBRID"** type (permanent formworks) could offer stiff competition especially if we consider that an increase in the market would make it possible for them to further reduce their amortization expenses and reduce costs to a level where traditional systems would no longer be able to compete.

It has to be pointed out that the industrialized solutions provide superior quality; both as pertains to details (see factory built houses) as well as to the material used (see permanent formworks).

Two avenues are particularly promising:

- For the **SINGLE DETACHED UNITS**, the improved **FACTORY BUILT MODULE** using stress skin box panel technology or the sandwich panel would mean savings as far as materials are concerned (positive impact on ecology since only one half the wood is required) and would use automation as pertains to labor savings; qualitative results similar to those obtained by the Swedish systems are to be expected.

- For the **MULTI-FAMILY SYSTEM**, concrete remains the simplest manner to provide soundproofing and fire protection; wood cannot compete except in conjunction with other materials and the performances are not really comparable; here the **PERMANENT FORMWORKS** system has demonstrated its advance although other solutions remain to be tried in Quebec.

The industrialized construction systems at the very least offer a valuable alternative which is qualitatively superior to traditional construction, the cost of which seems often to be protected by the security it represents in the eyes of builders, promoters and labor in general.

APPENDIX "A"

DESCRIPTIVE SHEETS FOR THE SYSTEM STUDIED

There is a two-page description of each of the twelve (12) systems studied below.

The first page stipulates the nature of the system using illustrations and comments on the sub-systems involved; all the elements not included in the systems chosen are dealt with in the traditional manner.

The second page contains the evaluation sheet per se and explains the results which are found in the tables in chapter 8.

The systems are presented in the order set forth in chapter 5:

1 TRADITIONAL BUILDING METHODS CURRENTLY USED IN QUEBEC

1.1 WOODFRAME
1.2 BEARING MASONRY
1.3 MONOLITHIC CONCRETE CAST ON SITE

2 MANUFACTURED SYSTEMS CURRENTLY AVAILABLE IN QUEBEC

2.1 LIGHT PANEL OPEN FRAMING
2.2 STRESSED SKIN BOX PANELS
2.3 COMPOSITE PANELS WITH RIGID INSULATION
2.4 MODULAR HOMES
2.5 PERMANENT FORMWORKS USING RIGID INSULATION

3 MANUFACTURED SYSTEMS LIKELY TO BECOME AVAILABLE IN QUEBEC

3.1 SANDWICH PANELS
3.2 PREFABRICATED CONCRETE PANELS

4 MANUFACTURED SYSTEMS USED ABROAD AND OF INTEREST FOR QUEBEC

4.1 LIGHT WOODFRAME PANELS ASSEMBLED BY AUTOMATION
4.2 MANUFACTURED MODULES WITH STRUCTUAL STEEL EDGES

A-1.1 WOODFRAME

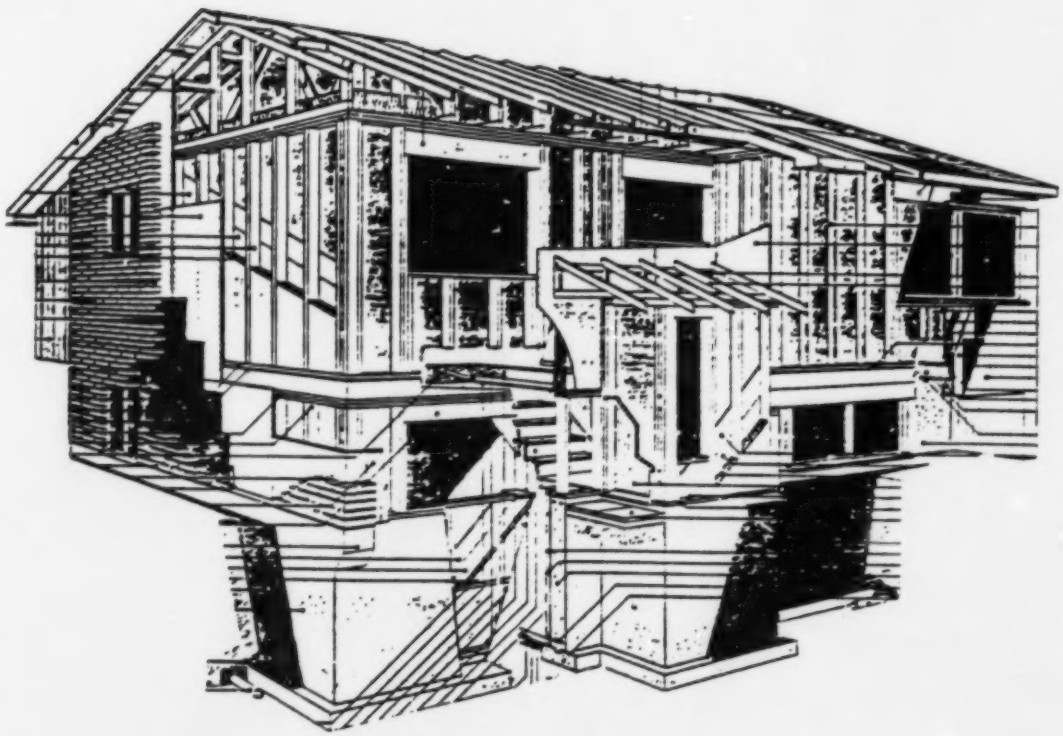
This is the most current solution in Quebec, both for the single family as well as the multi-family models (#3).

- **VERTICAL FRAME** using solid wood studs usually 16"c.c. so as to coincide with the 4' X 8' sheathing joints; **HORIZONTAL FRAME** using solid joists or added/composites trusses offering a span of 6 to 7 metres.

- Integrated **ENVELOPE:** wall sheathing/cladding - air barrier/thermal insulation interpolated (and superimposed) paper barrier/interior sheathing usually in gypsum board.

- **INTERIOR PARTITIONS** contributes to bracing effect and solidifies the frame; of a nature similar to the latter.

- Integrated electrical and mechanical **SERVICES.**



A-1.1 **WOODFRAME CONSTRUCTION** (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	749 $/m2
Cost of Row Housing Model:	618 $/m2
Cost of Low-Rise Multi-Family Model:	536 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Integration of all the sub-systems;	5
b- EXTENT OF INDUSTRIALIZATION: Generally Manual	0
c- DURATION OF WORK:	
- Single Detached Model: 8 weeks	0
- Row House Model: 8 weeks	1
- Low-Rise Multi-Family: 12 weeks	2
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Complete, due among other things to the flexibility of the material and of the method. Easy conversion, limited solely by the load bearing elements, although transfers are possible.	5 (uj:4)
e- QUALITY OF THE JOINT WORK: Limited by the movements of the material due to its organic nature and to its degree of humidity. Imprecision and instability due to nailing.	2
- Soundproofing: special measures to exceed STC 45 for the ceiling-floor and for the walls of the low-rise multi-family models.	
- Thermal Insulation: walls usually are R-20 and roof R-40, frame acting has partial thermal break.	

A.1.2 BEARING MASONRY &

a- **STEEL TRUSSES** (including the composite method) or

b- **PRESTRESSED HOLLOW SLABS**

Mainly for the **low-rise multi-family model**, occasionally for the **row house model** (#4).

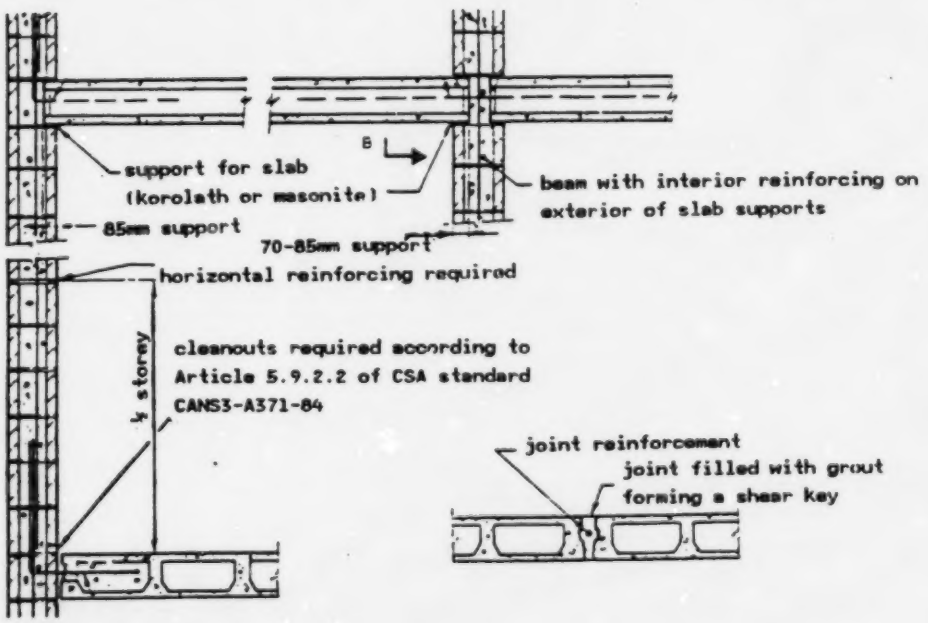
- **FRAME** using standard elements: concrete blocks installed manually, steel trusses or extruded prestressed concrete slabs (which require a crane).

  The **COMPOSITE** (#5) method is made up of a steel truss with an anchoring device for a concrete slab cast on site using temporary forms supported by the same truss. In the case of self-help construction, there's a possibility of using a light concrete block which has been tongue and grooved.

- **ENVELOPE:** possiblity of keeping the masonry visible by insulating from the inside, but with a thermal bridge at the meeting point of the wall-slab; otherwise, exterior siding and insulation against the exterior side of the block.

- **PARTITIONS:** gypsum board on light metal frame.

- **SERVICES:** electrical distribution integrated in the partitions.



(#4)

A.1.2 BEARING MASONRY (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	N/A
Cost of Row Housing Model:	706 $/m2
Cost of Low-Rise Multi-Family Model:	606 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Integration of frame and part of the envelope (cross walls) and the partitions. Accessibility to services with the composite option	2
b- EXTENT OF INDUSTRIALIZATION: Unit is produced by automation; prestressed trusses and slabs by mechanization, mortar and compressed concrete cast on site	1
c- DURATION OF WORK:	
- Single Detached Model: N/A	
- Row House Model: 9 weeks	0
- Low Rise Multi-Family: 14 weeks	0
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Diversity in planning, conversion limited by bearing walls and the slabs and to a lesser extent by the composite.	3
e- QUALITY OF THE JOINT WORK: Simplicity of the mortar joint, but variable precision. Distinction to be made here between masonry, interfaces with it (mortar) and what is independent of it.	3
- Water tightness conditioned by the application of the "rain screen" principle.	
- Soundproofing is ameliorated by the mass of the masonry, but the need remains to monitor the joints and to cover the furrings.	
- Thermal bridge at floors with slab if the masonry is exposed on the outside.	

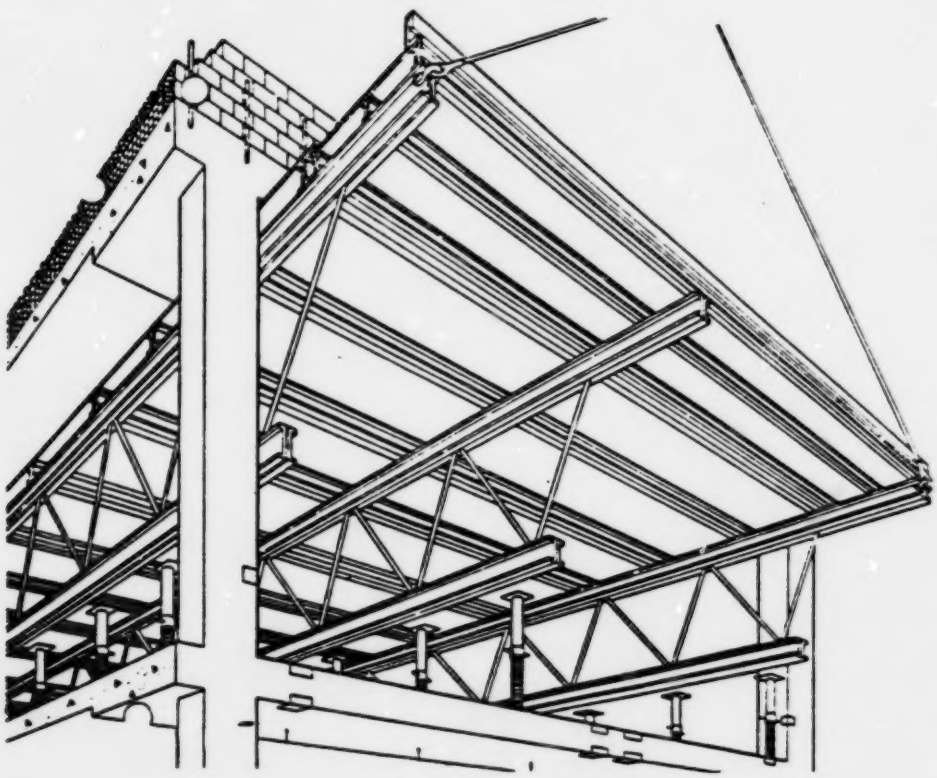
A.1.3 MONOLITHIC CONCRETE CAST ON SITE

Using traditional plywood forms or mechanized (travelling or other types) forms (#6);

Universally used for the high-rise multi-family, the monolithic concrete still remains very popular even for the low-rise multi-family model and for row housing in many countries; due to its strength, fireproofness and soundproofness.

- Monolithic high-rise and low-rise **FRAME** by definition; since the walls were generally in segments of sufficient length to meet the purely structual requirements, and the rest was filled in by concrete and gypsum blocks on metallic frame.

- **ENVELOPE, PARTITIONS AND SERVICES.**
  See bearing masonry.



A.1.3 MONOLITHIC CONCRETE CAST ON SITE (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	N/A
Cost of Row Housing Model:	701 $/m2
Cost of Low-Rise Multi-Family Model:	581 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Limited by the frame; possibility of leaving the end wall visible, but thermal bridge.	1
b- EXTENT OF INDUSTRIALIZATION: Manual but improved by modular/mechanized sheeting.	1
c- DURATION OF WORK:	
- Single Detached Model: N/A	
- Row House Unit: 10 weeks	0
- Low Rise Multi-Family: 15 weeks	0
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Complete; conversion limited by the frame.	3
e- QUALITY OF THE JOINT WORK: Monolithic nature of the frame produces a simple strong structure and the possibility of making "insertions" at the casting stage.	2
- Soundproofing: the frame alone provides soundproofing of STC 55 in the walls, and 45 for floors-ceilings.	
- Thermal break conditioned by an envelope completely covering the outside, i.e., no concrete visible on the outside.	

A.2.1 LIGHT PANEL OPEN FRAMING (flexible insulation)

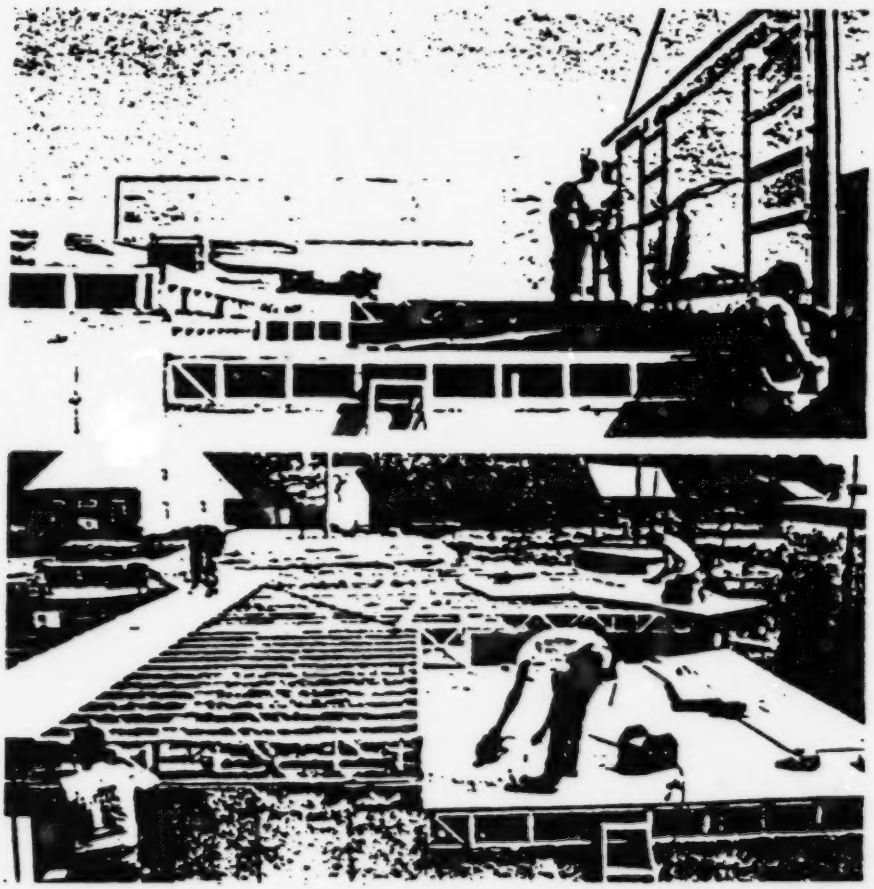
The walls and the floors-ceilings of the frame construction were produced in the factory in order to benefit from the inherent advantages of prefabrication (#8).

- **FRAME**: the most elementary version consists of factory building the same wall as on site, i.e., 2" X 6" studs and bracing. The same is true for the floor-ceiling.

- **ENVELOPE**: addition of (flexible) insulation, of the air barrier and sometimes of rough finish work.

- **PARTITIONING**: same as for the frame.

- **SERVICES**: possibility of integrating electrical distribution.



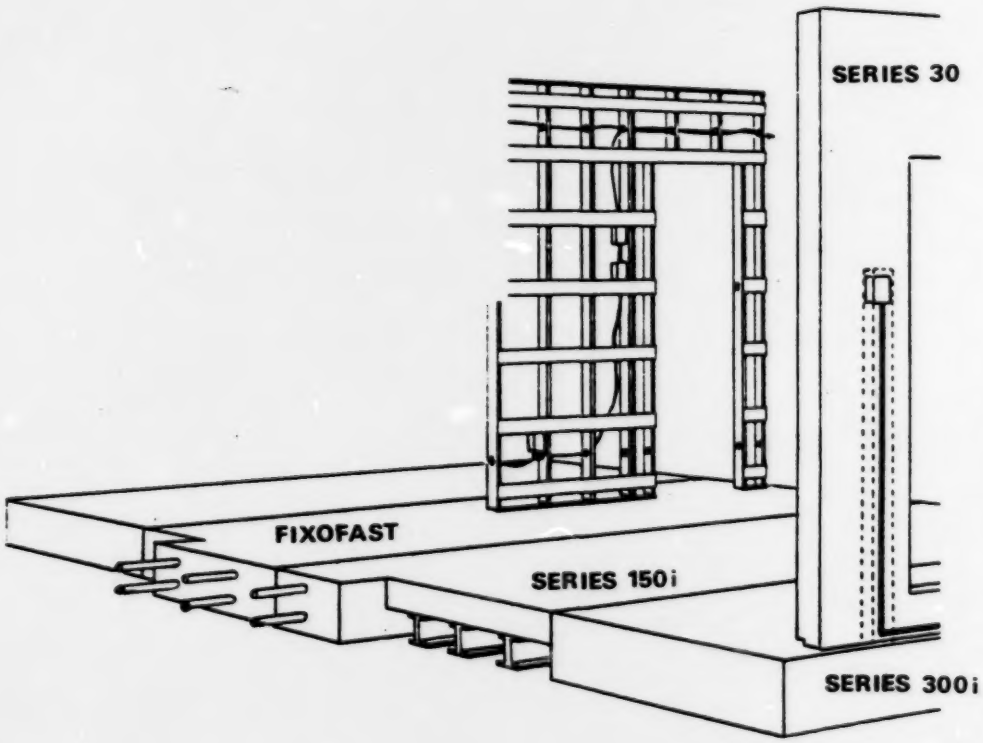
A.2.1 LIGHT PANEL OPEN FRAMING (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	702 $/m2
Cost of Row Housing Model:	587 $/m2
Cost of Low-Rise Multi-Family Model:	527 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Partial integration of the frame/envelope and partitions (steel cladding).	2
b- EXTENT OF INDUSTRIALIZATION: Traditional method merely making use of the advantages of the factory.	1
c- DURATION OF WORK:	
- Single Detached Model: 7 weeks	1
- Row House Unit: 6 weeks	4
- Low Rise Multi-Family: 10 weeks	5
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Comparable to woodframe model erected on site.	5 (uj:4)
e- QUALITY OF THE JOINT WORK: Tolerance and instability problems produced by nailing. The other conditions are similar to the traditional woodframe systems.	2

A.2.2 STRESSED SKIN BOX PANELS

Use of stressed skin box panels made entirely of wafer board: savings on material used, integration of insulation/wiring and simplification of assemblage on site. The adhesive materials (usually phenolic based) create a continuity which transforms ribs and partitions into a series of boxes; with the result that the ribs can be built with the same thin material as the partitions (#9).

- **FRAME:** horizontal and vertical frame for the boxes, finish work to be completed using the traditional method.
- **ENVELOPE:** integrated into the frame, thermal insulation incorporated in the box; siding to be installed on site.
- **PARTITIONING:** frame panels with furrings to attached to the gypsum board.
- **SERVICES:** electrical distribution system incorporated.



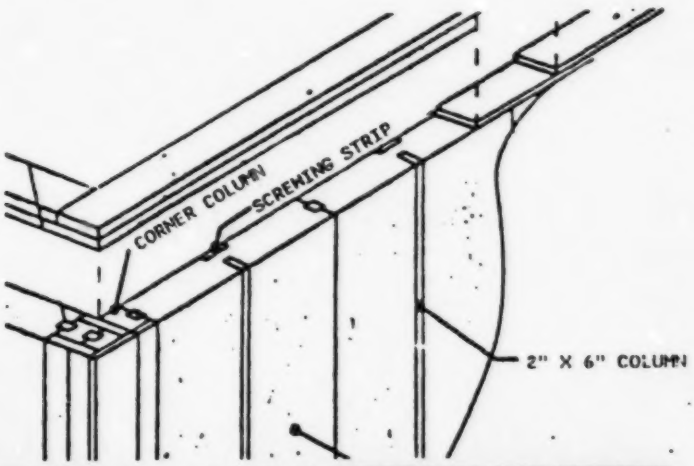
A.2.2 STRESSED SKIN BOX PANELS (cont'd)

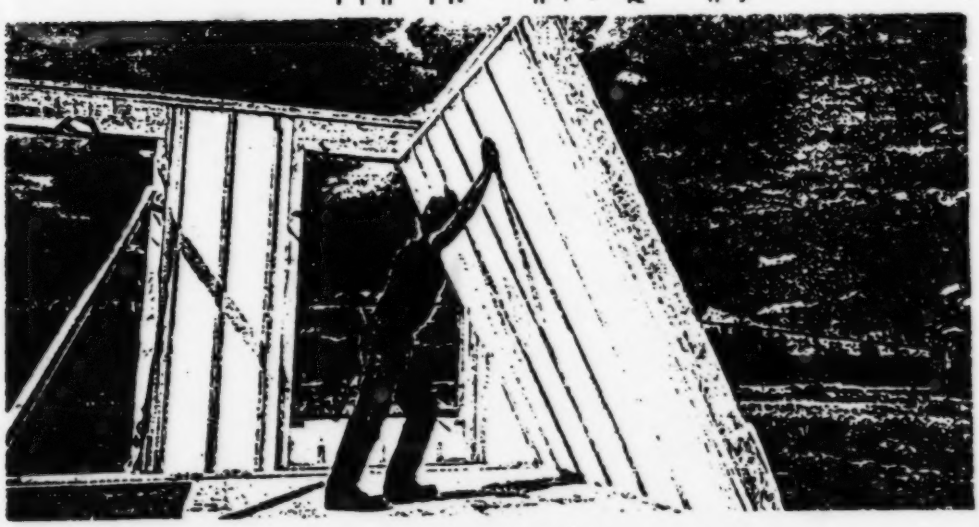
1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	821 $/m2
Cost of Row Housing Model:	731 $/m2
Cost of Low-Rise Multi-Family Model:	N/A
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Partial integration of the frame/envelope and partitions (siding to be added)/services (electrical distribution).	3
b- EXTENT OF INDUSTRIALIZATION: Prefabrication as far as the process is concerned and reproduction as far as the material is concerned (the continuity between the ribbing and the partitions provided by the adhesive doubles the structual performance).	2
c- DURATION OF WORK:	
- Single Detached Model: 6 weeks	3
- Row House Unit: 7 weeks	3
- Low Rise Multi-Family: N/A	
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: The geometry of the boxes facilitates the composition but the complexity of the plan and of the section increases the number of rooms. Difficulty to modify or to intervene at the box level.	3
e- QUALITY OF THE JOINT WORK: Sprayed polyurethane to treat the joints. Stability superior to traditional frame due to the rigidity of the box.	4
- Soundproofing: Not appropriate for the multi-family model, a double partition is necessary for the row house model	
- Thermal Insulation: walls R-20 and roof R-32	

A.2.3 COMPOSITE PANELS WITH RIGID INSULATION

Using of extruded polystryrene panels as a permanent frame to install the wood studs and also as a thermal break: ingenious way of simplifying factory production while at the same time maximizing energy conservation (#10). These vertical panels are generally completed by slabs of a similar nature or by open web trusses with plywood apron.

- **FRAME:** studs separated by a thermal break.
- **ENVELOPE:** only the insulation is integrated.
- **PARTITIONING:** generally not part of the system, i.e., traditional.
- **SERVICES:** a recessed polystyrene extrusion facilitates the installation of the wiring horizontally.





A.2.3 COMPOSITE PANELS WITH RIGID INSULATION (cont'd)

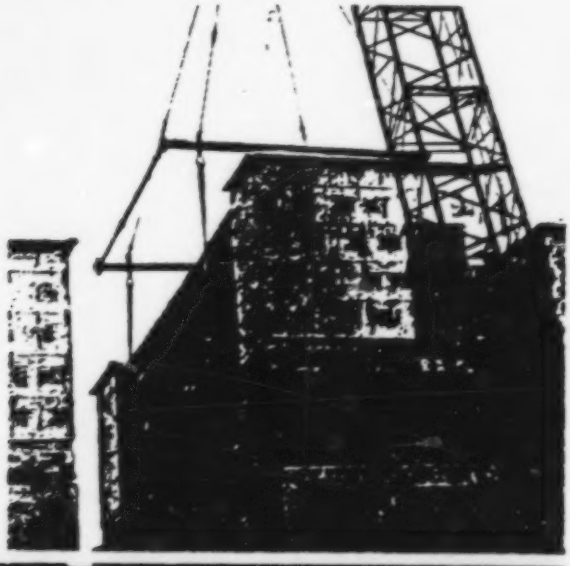
1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	758 $/m2
Cost of Row Housing Model:	633 $/m2
Cost of Low-Rise Multi-Family Model:	547 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Partial integration of the frame/envelope (siding to be added).	1
b- EXTENT OF INDUSTRIALIZATION: Prefabrication; simplification of the assemblage through the use of extruded polystryrene panels as a permanent frame; sub-contracting out of supply of polystyrene and trusses.	2
c- DURATION OF WORK:	
- Single Detached Model: 8 weeks	0
- Row House Unit: 8 weeks	1
- Low Rise Multi-Family: 12 weeks	2
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Comparable to the traditional system.	5 (uj:4)
e- QUALITY OF THE JOINT WORK: Tolerance problems, often due to the difficulty of nailing the sill perpendicularly due to the presence of rigid insulation.	3
- Thermal Insulation Code: Wall R-20	

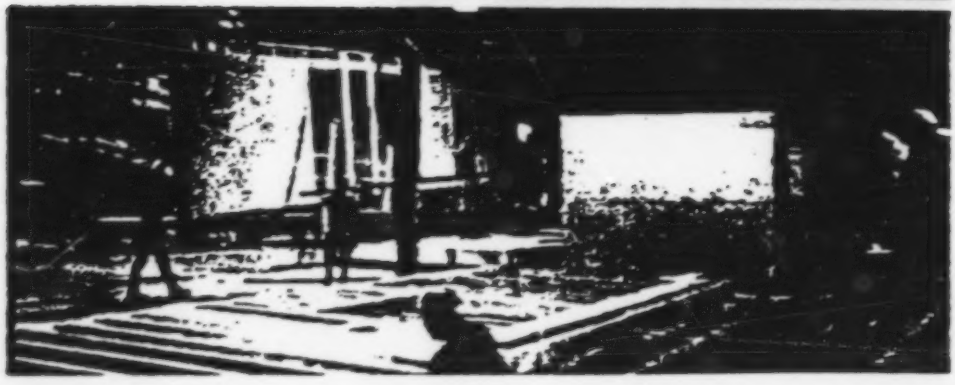
A.2.4 MODULAR HOMES

The only completely factory built approach in Quebec at the present time. Tridimensional woodframe modules erected and finished in the factory. The typical factory adapts the principle of the assembly line fuelled perpendicularly by the sub-assembly of the component parts; this essentially involves fastening the panels together, integrating the services and adding the interior and exterior cladding (#11).

Geometry is governed by the road clearance (16' width) but construction quality is better to resist handling and excellent soundproofing quality is produced by the double walls which are created once two modules are placed side by side. Site work is reduced to a simple operation of hooking up and finish work (taping of gypsum board joints/painting/flooring/etc...).

Integration **FRAME/ENVELOPE/PARTITIONING/SERVICES/EQUIPMENT.**





A.2.4 **MODULAR HOMES** (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	693 $/m2
Cost of Row Housing Model:	757 $/m2
Cost of Low Rise Multi-Family Model:	650 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Integration of all sub-systems.	5
b- EXTENT OF INDUSTRIALIZATION: Complete prefabrication, mechanization of main stages: assembly line and sub-assemblage, pneumatic tools and lifting devices. Transportation by sub-contracting (one module per lorry).	2
c- DURATION OF WORK:	
- Single Detached Model: 5 weeks	4
- Row House Unit: 5 weeks	5
- Low Rise Multi-Family: 9 weeks	5
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Governed by the geometry of the module and by the road clearance (maximum width 4.85m and maximum clearance beyond the lorry (3.6m).	3
e- QUALITY OF THE JOINT WORK: Conditioned by the nature of the wood, but better accuracy due to factory conditions. Additional stability due to drying of wood and to glued assemblage, since transportation conditions have more effect on the joints than the useful life of the building.	3
- Water Tightness: Inter-module pointing to be controlled; particularly through the use of cover strips, to avoid capillarity.	
- Soundproofing: The only way to insure STC-55 in wood, due to the double partitions.	
- Thermal Insulation: Wall R-20 and roof R-40.	

A.2.5 PERMANENT FORMWORKS USING RIGID INSULATION

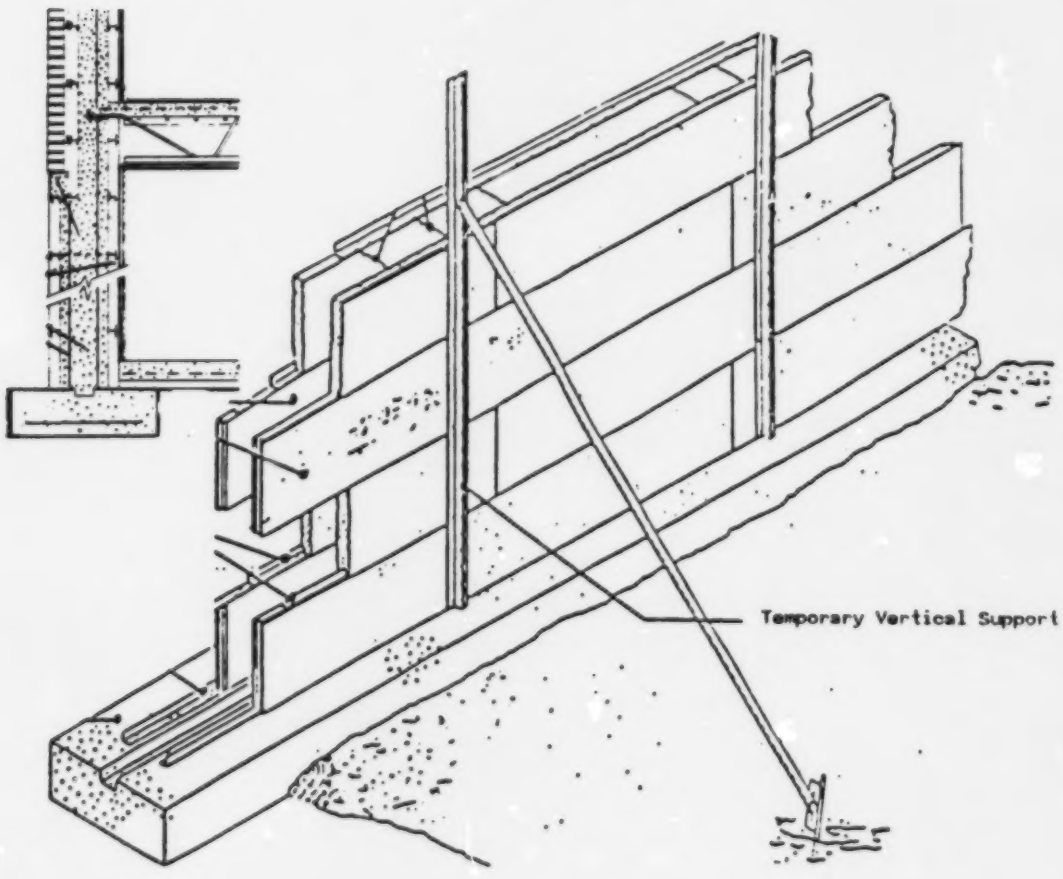
Simplication of the efforts involved in casting concrete on site using hollow polystyrene mega-blocks which are easily tongue and grooved as permanent formworks (i.e. no forms to put up then take down); continual thermal break and ease with which cladding is installed through the use of angle irons inserted between the blocks (#12).

VERTICAL monolithic concrete **FRAME**; various **HORIZONTAL FRAME** options (hollow prestressed slab, compressed composite steel-concrete truss, concrete truss and casebay, wood truss for the single family, etc...).

ENVELOPE: siding to be attached using the angle irons.

PARTITIONING: both the system and the traditional method are used.

SERVICES: not included in the system.



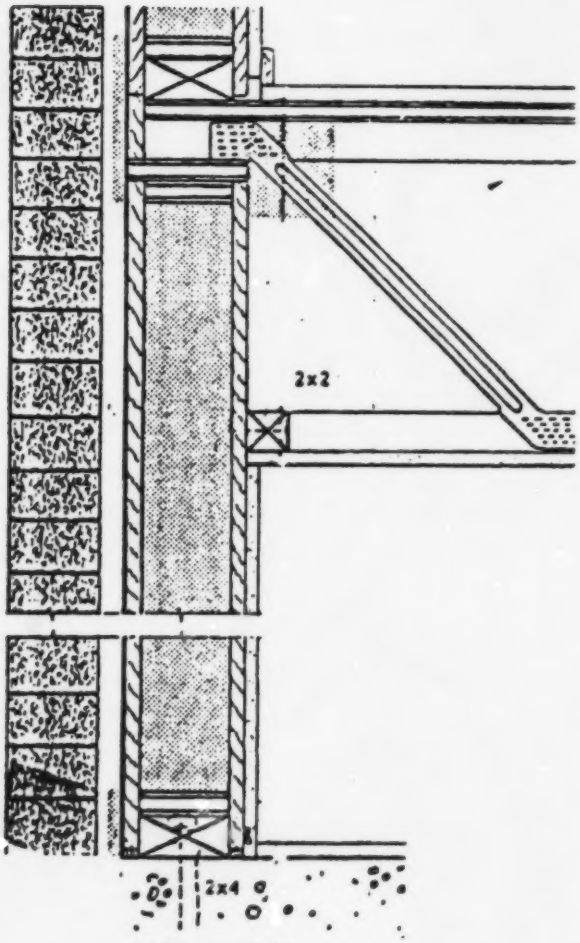
A.2.5 PERMANENT FORMWORKS USING RIGID INSULATION (cont'd)

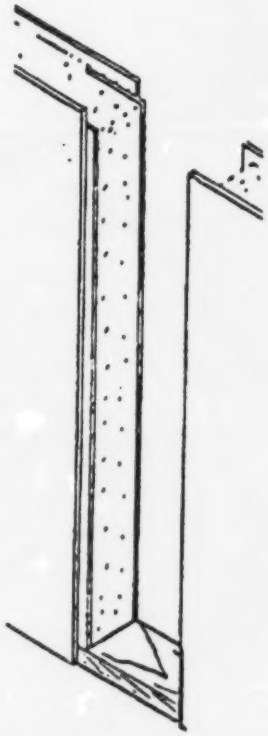
1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	761 $/m2
Cost of Row Housing Model:	655 $/m2
Cost of Low Rise Multi-Family Model:	592 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Integration of the frame and the envelope's thermal insulation component.	2
b- EXTENT OF INDUSTRIALIZATION: "Reproduction" as pertains to the systematic assemblage of the polystyrene mega-blocks used both as permanent formworks and as insulation; the mega-blocks are manufactured through sub-contracting.	2
c- DURATION OF WORK:	
- Single Detached Model: 9 weeks	0
- Row House Unit: 9 weeks	0
- Low Rise Multi-Family: 14 weeks	0
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Comparable to traditional concrete, conditioned by the nature of the floor-ceiling.	3
e- QUALITY OF THE JOINT WORK: Ingenuity and simplicity of the "building block" arrangement. Finish work contingent on proper installation of siding using the angle irons.	5
- Soundproofing: S.T.C. 60	
- Thermal Insulation: Wall R-30 and roof variable.	

A.3.1 SANDWICH PANELS

Load bearing panels made up of rigid insulation core which is injected under pressure between two sheets of plywood, particle board, metallic sheathing or asbestos-ciment. The joint between the panels is tongue and grooved (#13).

- **FRAME:** walls and floors using these sandwich panels.
- **ENVELOPE:** exterior siding and interior finish to be added on site.
- **PARTITIONING:** using sandwich panels or the traditional method.
- **SERVICES:** ducts to integrate the wiring.





A.3.1 **SANDWICH PANELS** (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	749 $/m2
Cost of Row Housing Model:	618 $/m2
Cost of Low Rise Multi-Family Model:	536 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Partial intergration/frame/envelope/partitions (without the siding).	2
b- EXTENT OF INDUSTRIALIZATION: . Prefabrication through injection under pressure; extruded joint obtained using lateral pockets.	2
c- DURATION OF WORK:	
- Single Detached Model: 7 weeks	1
- Row House Unit: 6 weeks	4
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Comparable to all light panels, limited conversion due to the fact that these are not frame panels.	3
e- QUALITY OF THE JOINT WORK: Tongue and grooved joints; ingenious, great precision in assemblage and integral bracing.	5
- Waterproofing: Provided by the continuity and overlapping of the joints.	
- Soundproofing: S.T.C. 55 insured by gypsum on metallic furrings.	
- Thermal Insulation: Wall R-20 due to the continual thermal break provided by the rigid insulation and the insulation inserted between the studs.	

A.3.2 PRECAST CONCRETE PANELS

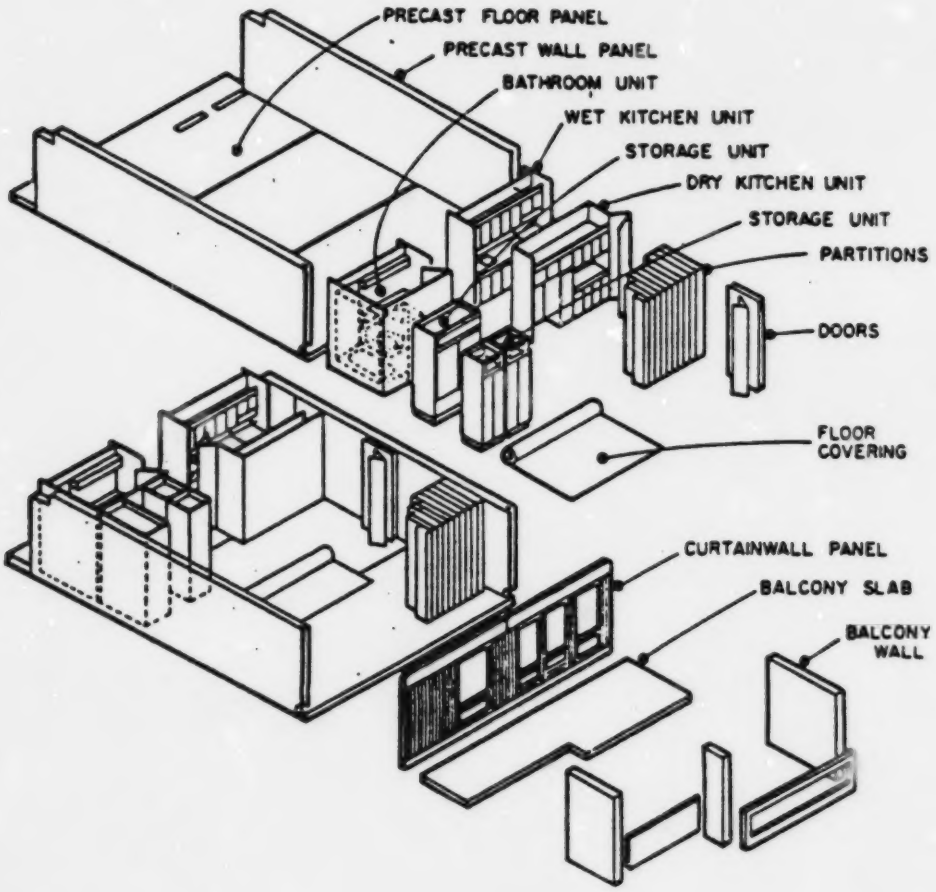
The prestressed slabs and the composite steel-concrete trusses make it possible to obtain spans of 6 to 8 metres, i.e., sufficient spans to cover one complete unit between the two walls and to produce a joint-area ratio within profitable limits. Pointing is nevertheless sophisticated (bolted and/or welded) and difficult handling conditions in terms of lorries and cranes (#14). Justified uniquely in the case of the low rise multi-family model.

- **VERTICAL FRAME** based on bearing walls, usually cross-walls and **HORIZONTAL FRAME** based on prestressed slab and composite truss in compressed concrete.

  - **ENVELOPE:** concrete-rigid insulation sandwich panel or the traditional method.

  - **PARTITIONING:** traditional (gypsum board on light steel frame).

  - **SERVICES:** not included in the system.



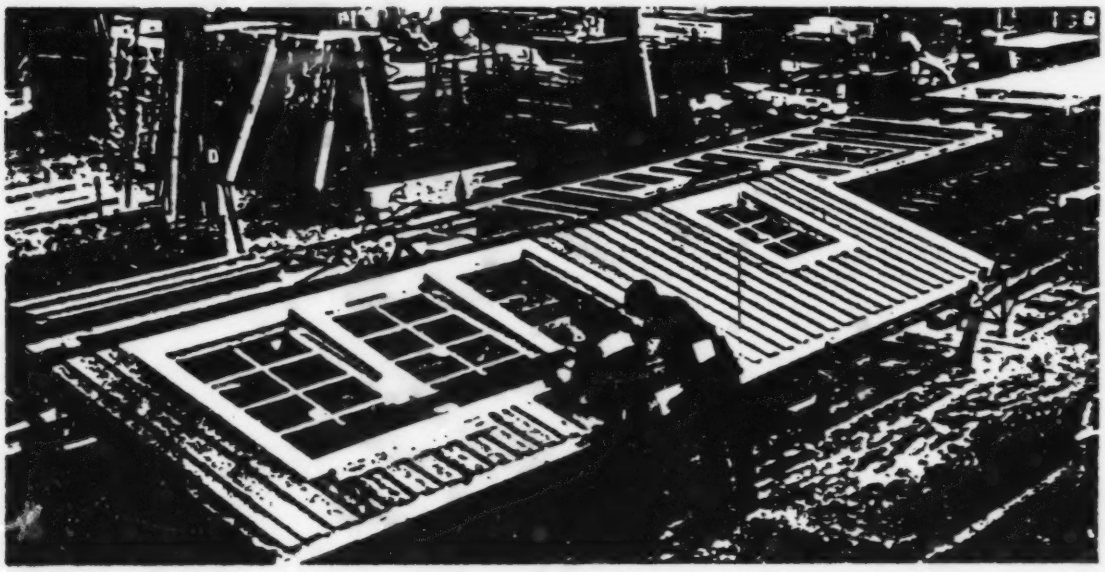
A.3.2 PRECAST CONCRETE PANELS (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	N/A
Cost of Row Housing Model:	802 $/m2
Cost of Low Rise Multi-Family Model:	627 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Partial integration/frame/envelope (end walls and sandwich lintels).	2
b- EXTENT OF INDUSTRIALIZATION: Prefabrication and mechanization. Factory: mechanized forms, machinery to prepare concrete and for lifting. Transportation by sub-contracting.	2
c- DURATION OF WORK:	
- Single Detached Model: N/A	
- Row House Unit: 7 weeks	3
- Low Rise Multi-Family Model: 11 weeks	3
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Conditioned by the cross-walls (span of 6 to 7.5M) and the slabs.	3
e- QUALITY OF THE JOINT WORK: Solid and relatively simple pointing using bolted angle irons with oblongs for tolerance and/or welding; ductility to resist earthquakes. Tolerances and architectural preparation of the interfaces are done with care.	3
- Waterproofing: Caulking and decompression space.	
- Soundproofing: R-55	
- Thermal Insulation: Envelope R-20 and roof R-40.	

A.4.1 LIGHT WOODFRAME PANELS ASSEMBLED BY AUTOMATION

Opportunity to evaluate and compare the Swedish panels produced by automation and entirely factory finished. Applicable above all to the single family model (#15).

The intergration of the sub-systems is similar to that for prefabricated panels pointed out in 4.2; we do have to point out, however, that this system produces a clearly superior level of precision, thermal insulation, finish work and durability.



A.4.1 LIGHT WOODFRAME PANELS ASSEMBLED BY AUTOMATION (cont'd)

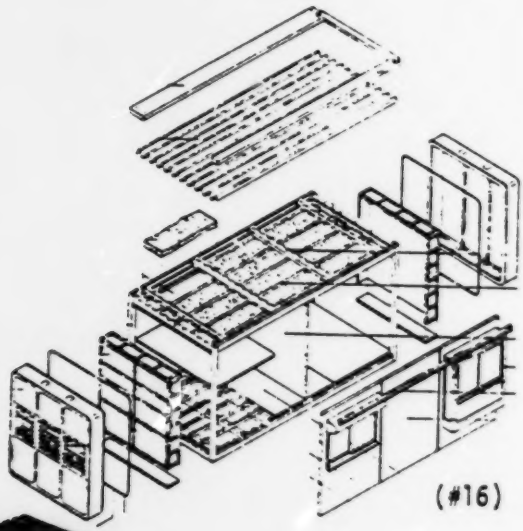
1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	757 $/m2
Cost of Row Housing Model:	719 $/m2
Cost of Low Rise Multi-Family Model:	684 $/m2
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM:	3
Partial intergration/frame/envelope/partitioning/services (electrical distribution).	
b- EXTENT OF INDUSTRIALIZATION:	3
Complete automation.	
Assembly line developed, automized as pertains to manufacturing and handling.	
c- DURATION OF WORK:	
- Single Detached Model: 5 weeks	4
- Row House Unit: 5 weeks	5
- Low Rise Multi-Family Model: 9 weeks	5
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY:	5 (uj:4)
Participation of the user in planning through the Computer Assisted Design/Manufacturing.	
Conversion comparable to traditional construction.	
e- QUALITY OF THE JOINT WORK:	5
Great precision provided by automation, superior to traditional construction method due to the quality of the materials and the type of assembly.	
- Soundproofing: Two walls required to reach STC-55 in the multi-family models.	
- Thermal Insulation: Walls R-35 and roof R-73.	

A.4.2 MANUFACTURED MODULES WITH STRUCTUAL STEEL EDGES, i.e., Modules with para-container dimensions which can be opened in 6 directions.

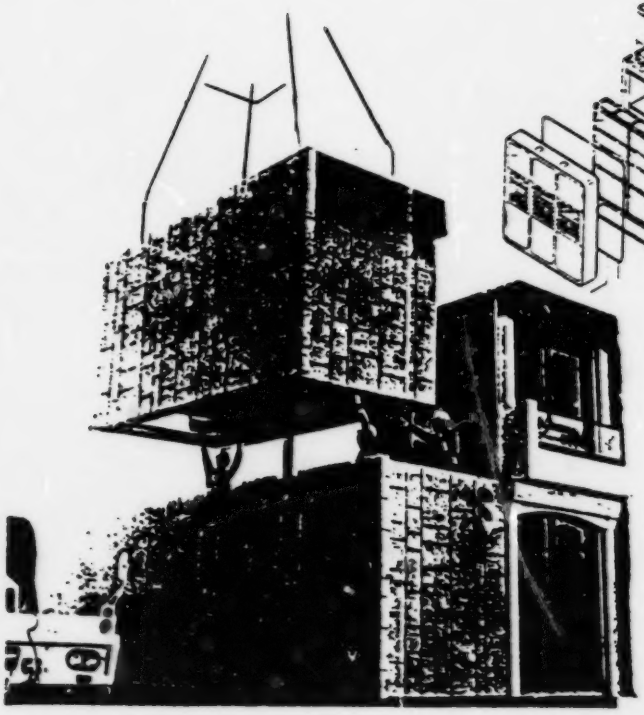
The highest degree of industrialization involving continuous production in the world, direct application of the principles of the assembly line used in the production of the automobile. Factory manufactured modules with structual steel edges making it possible to join up two modules to create a large room. The para-container dimensions are the consequence of restrictions imposed by the Japanese road clearance; in this regard, Quebec manufacturers have an important advantage since a module can measure 16' X 48'.

INTEGRATION FRAME/ENVELOPE/PARTITIONING/SERVICES/EQUIPMENTS

The modules can be adapted to multiple variations and this makes it possible for them to generate an infinite number of models: this depends on the individual plan which is based on the needs and the taste of the purchaser. The purchaser can even participate in the planning of his house using CAD software (Computer Assisted Design) respecting the standards and regulations of the system.



(#16)



(#17)

A.4.2 MANUFACTURED MODULES WITH STRUCTUAL STEEL EDGES (cont'd)

1- ECONOMIC EVALUATION	
Cost of Single Detached Model:	955 $/m2
Cost of Row Housing Model:	1050 $/m2
Cost of Low Rise Multi-Family Model:	N/A
2- TECHNICAL EVALUATION	
a- MAGNITUDE OF THE SYSTEM: Integration of all the sub-systems.	5
b- EXTENT OF INDUSTRIALIZATION: Automation of the assembly process, robotization of the main components.	4
c- DURATION OF WORK:	
- Single Detached Model: 4 weeks	5
- Row House Unit: 4 weeks	5
- Low Rise Multi-Family Model: N/A	
3- QUALITATIVE EVALUATION	
d- ARCHITECTURAL FLEXIBILITY: Facilitated by the geometry of the modules which allows for the opening of all the partitions due to the structure. Participation of the user in the planning through CAD software.	4 (uj:3)
e- QUALITY OF THE JOINT WORK: High degree of precision and solidity of the bolted joint.	4

APPENDIX "B"

PLANS FOR THE ARCHITECTUAL MODULES AND SUMMARY SPECIFICATIONS

The layout of the seven (7) model plans used for the modelization is shown on the following pages using a scale of 1 to 100 in the case of the single detached model and 1 to 150 in the case of the low rise multi- family model. All this is accompanied by summary specifications designed to more closely identify the "moderate cost" level which was the goal of the study.

As pointed out previously, the compatibility among the plans and the construction systems chosen is indicated in table 6.3.

SERIES "A"

- Single Detached Model
- Row Housing Model
- Low Rise Multi-Family Model

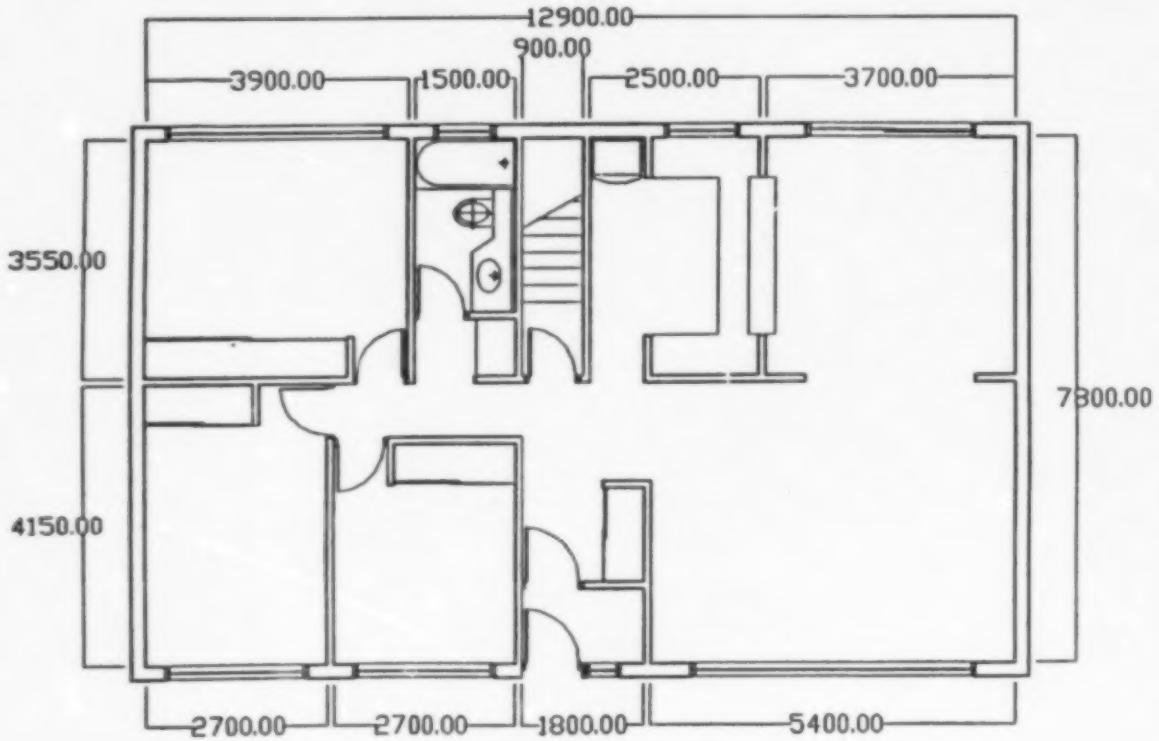
SERIES "B"

- Single Detached Model
- Row Housing Model
- Low Rise Multi-Family Model

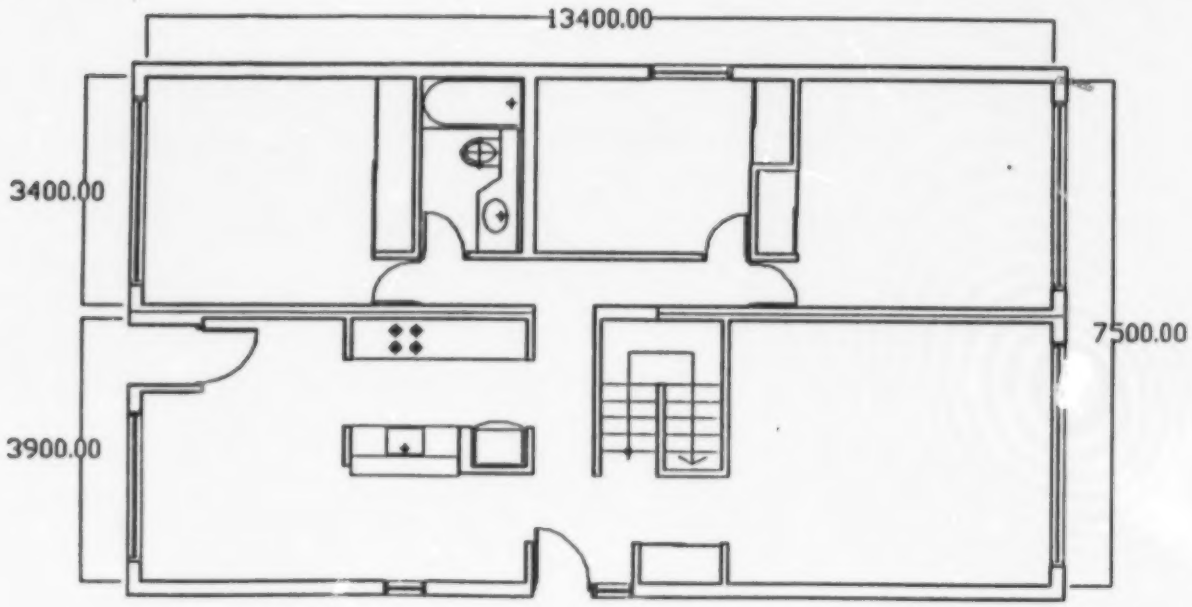
SERIES "C"

- Single Detached and Row Housing Models

TYPE A
SINGLE DETACHED MODEL
100.6 m2

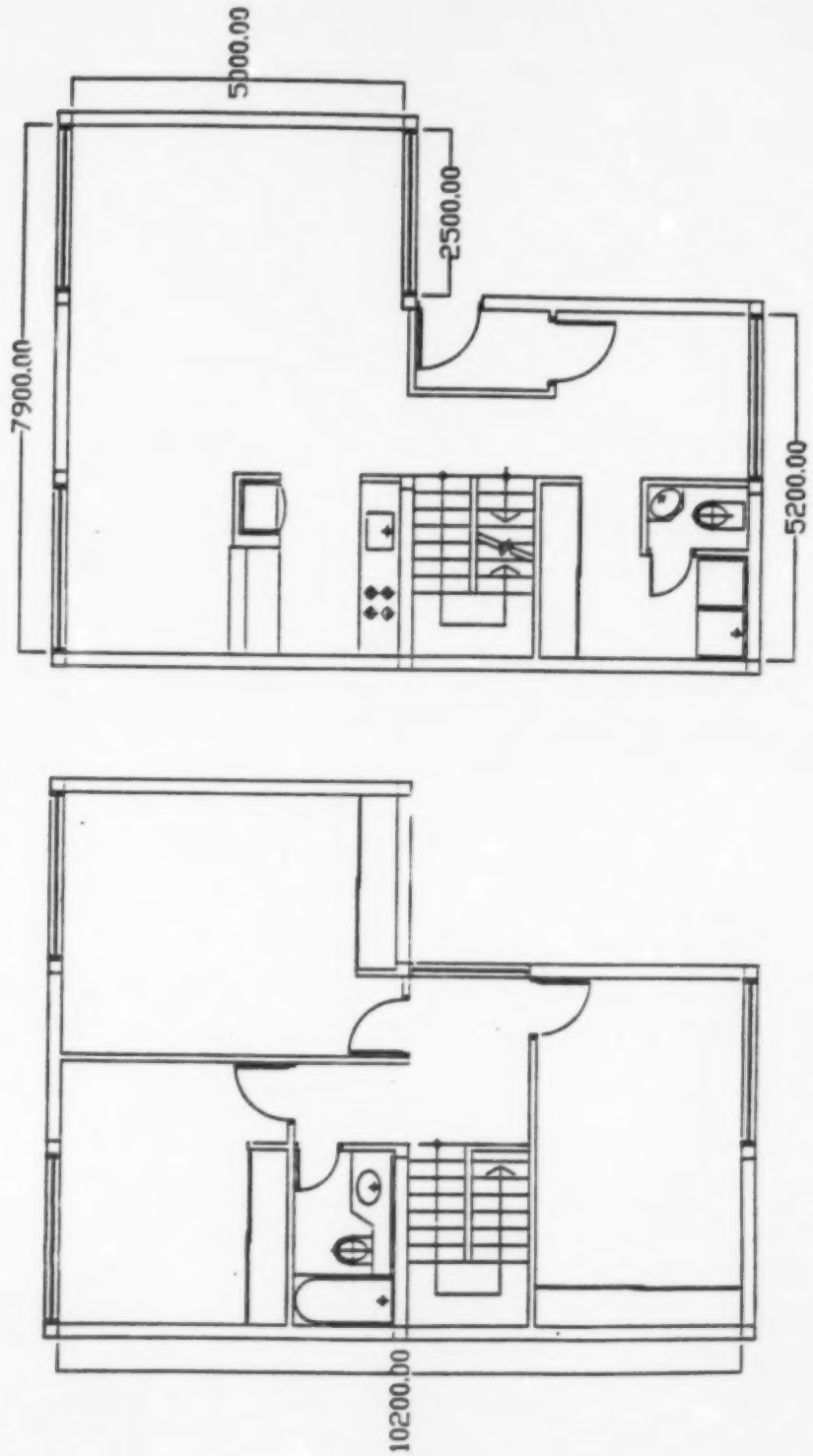


TYPE B
SINGLE DETACHED MODEL
100.5 m2



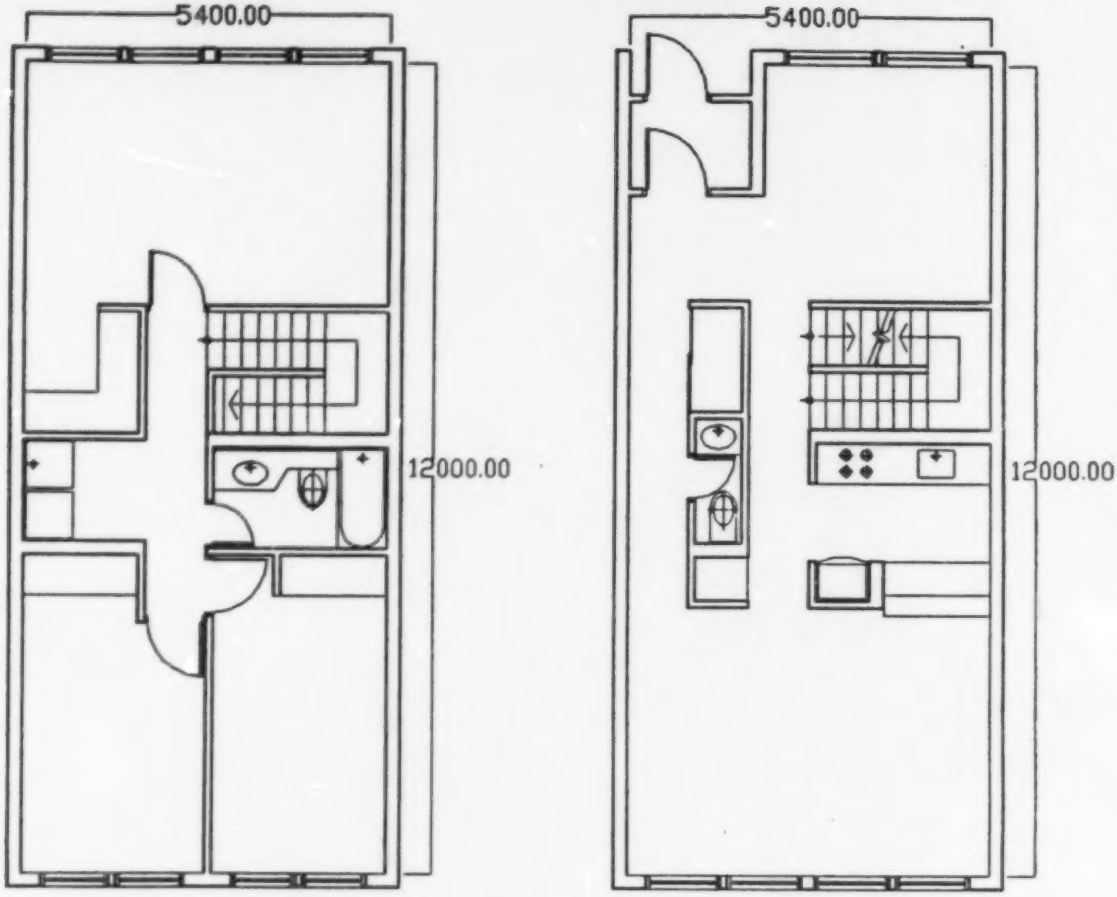
TYPE C
SINGLE DETACHED AND
ROW HOUSING MODELS

125 m2



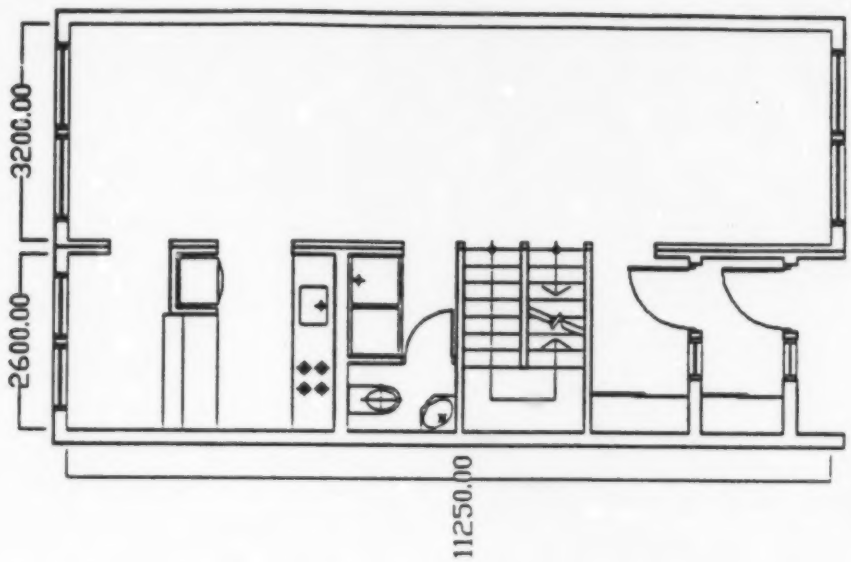
TYPE A
ROW HOUSING MODEL

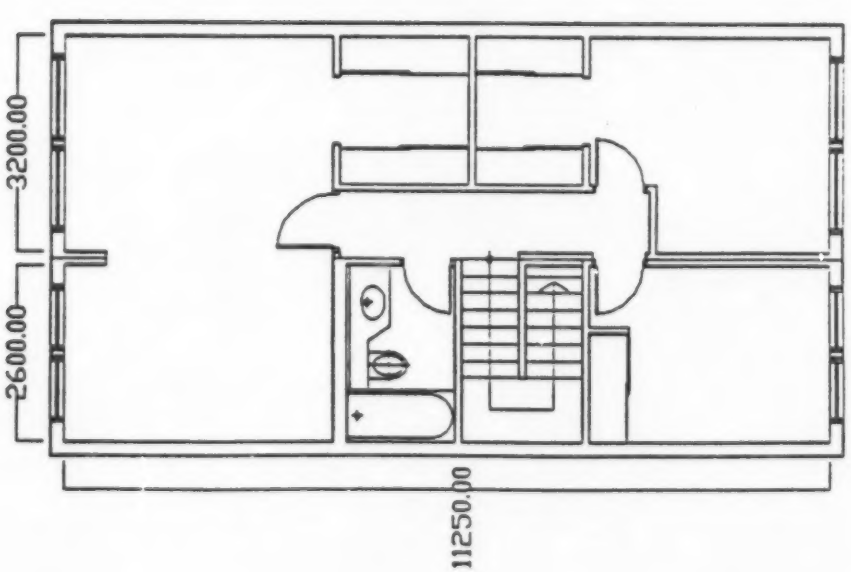
129.6 m2



TYPE B
ROW HOUSING MODEL

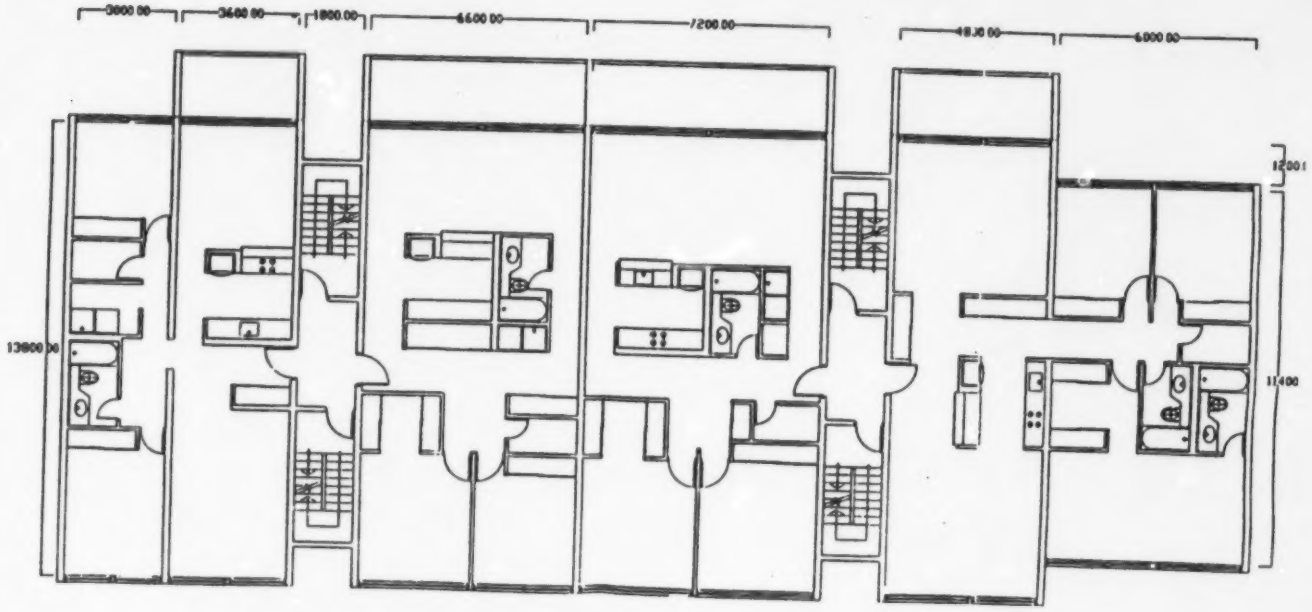
130.25 m2





TYPE A
LOW RISE MULTI-FAMILY MODEL

SMALL 2-BEDROOM	SMALL 2-BEDROOM	LARGE 2-BEDROOM	LARGE 3-BEDROOM
91.08 m2	91.08 m2	99.36 m2	134.64 m2

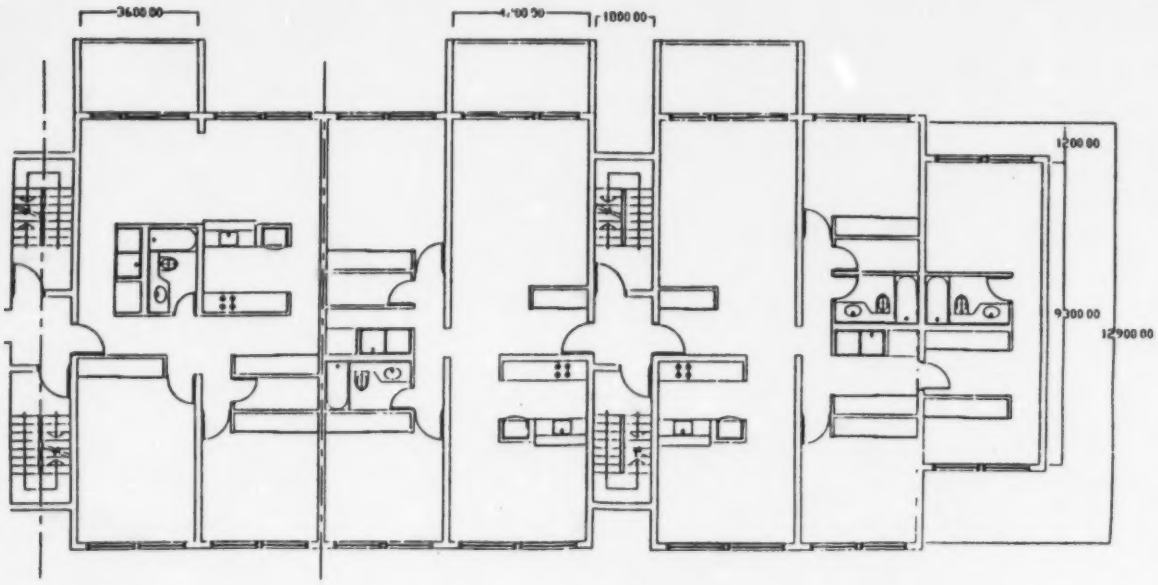


TYPE B
LOW RISE MULTI-FAMILY MODEL

SMALL 2-BEDROOM
92.88 m2

LARGE 2-BEDROOM
100.62 m2

LARGE 3-BEDROOM
134.1 m2



SUMMARY SPECIFICATIONS

Due to the large number of options offered both under the traditional construction as well as the factory built construction methods, we decided to limit the study to the basic building level, with reference to the summary specifications which follow for information purposes. Thus the study deals with the "moderate cost" market segment and for each of the three types of dwellings studied.

1- **FRAME**
Foundation and infrastructure in reinforced concrete, waterproofed and insulated from the outside (R-15). Superstructure complies with the codes, one hour fire resistence.

2- **ENVELOPE**
Composition of the "rain screen" walls (completely or at the joints) with air barrier/thermal insulation (R-20)/continuous vapor barrier.

Exterior siding and masonry, stucco or metal siding.

Double glazed windows with frames in aluminum with thermal breaks, minimum 20% opening, height of 48".

Metal entrance door, R-10 insulated, double glazed patio door or double doors.

Roof R-40 in asphalt shingles on plywood and trusses.

3- **PARTITIONING**
Partitions in gypsum board on wood studs where woodframe is used, on metal raisers for concrete/masonry/metal frame. Common or party walls STC 55.

Common ceilings STC 55.

Entrance door in solid wood, hollow core for interior doors as well as for the cupboards. Frames in metal.

4- **SERVICES**
Mechanical and electrical services in compliance with the codes. Natural ventilation promoted by double orientation of each unit.

5- **EQUIPMENT**
Common stairs in metal with concrete purlins; in wood on the inside of the unit.

Kitchen and bathroom furniture in MCP, standard appliances.

N.B. Finish work in the basement as well as landscaping are not included in this study.

APPENDIX "C"

EXPLANATORY NOTES FOR THE ECONOMIC EVALUATION

The construction lots for each of the systems listed in the 3 comparative tables were broken down so as to be able to compare as objectively and fairly as possible, the unit cost per square meter, in relation to the traditional wood construction.

The costs accompanied by an "ASTERISK" (*) represent construction lots affected by the various systems. Those represented by an "S" are lots which are entirely covered by the system.

The overhead includes:

Temporary services (electricity, heating, telephone, water) garbage removal, rental fees for a site trailer, for toilets, for specialized equipment, construction permit, insurance, professional fees (architect, engineer, surveyor), interim financing, cost of transporting factory built elements/modules, contingencies and other miscellaneous fees.

1.1 TRADITIONAL IN WOOD

The costs established for this construction type are used as a point of comparison for all the other systems included in this study.

1.2 BEARING MASONRY

It is not realistic to consider this type of construction for the small single detached model.

For the other two (2) systems studied, the cost of the system is determined by masonry work for the exterior walls and the bearing walls as well as the use of hollow slabs for the floors.

- Cost of the bearing walls: $65.00/m2
- Cost of the hollowed slabs: $81.00/m2

The differential costs are justified by:

a) The wood elements are limited solely to supplying and installing the structure and insulating the roofs and interior stairs.

b) The additional gypsum board elements on metallic studs with insulation for the exterior walls, without insulation for the interior non-load bearing partitions, on furrings for the other walls and ceilings.

1.3 CONCRETE CAST ON SITE

This method is mainly used for commercial and industrial purposes. It makes use of the traditional forms and the structure is entirely made up of concrete cast on site.

Cost of the formworks:

- Footing, fondations = $50.00/m2
- Shear walls = $15.00/m2
- Floor slabs = $35.00/m2
- Slab finish = $ 5.00/m2
- Average cost of concrete = $80.00/m3

The differential costs reflect the same situation as the bearing masonry.

2.1 OPEN WOODFRAME PANELS

This type of construction involves all the wood frame as well as all the materials necessary to close the envelope. The walls are delivered on site with the insulation, paper barriers, as well as the interior and exterior furrings. "Rough" stairways in wood as well as the supply and installation of windows are also included in the system.

Based on the information collected, the savings on the material and labor necessary to complete the whole envelope represent 10 to 20% depending on the complexity of the plans for the single detached model. The use of lifting equipment becomes essential when dealing with the low rise multi-family and the row housing models.

2.2 STRESSED SKIN BOX PANELS

This type of construction was not considered for the low rise multi-family models given the importance granted to soundproofing and fireproofing between the various units to meet the standards identified in the specifications.

The cost of the system is established based on:

- Exterior walls: = $69.00/m2
- Box panels for floors: = $78.50/m2
- Panels for roof: = $82.00/m2

The differential costs are explained by:

a) Additional gypsum board elements necessary on metal studs for the interior partitions and on metal furrings for the exterior walls.

b) Material and labor for the interior stairway and insulation of the foundation walls.

2.3 WOOD PANELS WITH RIGID INSULATION

This type of construction is limited solely to the exterior walls of the models studied.

However, the party walls were considered as being exterior and independent walls to increase the acoustic performance between the units.

The cost of the system was calculated based on a figure of $30.50/m2 for the exterior walls.

The material costs are reduced considering that the wood and insulation for the exterior walls are included in the cost of the system.

2.4 MODULAR HOMES

The prefabrication of modular homes is the system which groups together the largest number of construction lots. On the other hand, lifting equipment is necessary to install the houses on their foundations.

The differential costs are explained by:

- Simple electrical hook-ups
- Underground plumbing and hot water tanks
- Basement stairs and insulation of foundation walls
- Gypsum board joints

2.5 PERMANENT FORMWORKS

The cost of the system includes:

- The structual envelope in concrete from the footing to the roof
- Forms with permanent expanded polystyrene insulation with furrings
- Steel trusses with 3" concrete floor for the multi-family model and wood trusses with 5/8" tongue and grooved plywood in the case of the single detached and row housing models
- Slab on grade and finish
- Steel stairway for the multi-family model, in wood for the single family model
- Installation of doors and windows.

The differential costs are explained by:

- Materials and labor for the work on the roof
- Gypsum board elements on metal studs for the interior partitions.

3.1 SANDWICH PANELS

Given that the sandwich panel system has just been introduced in Quebec, the data collected are not sufficient to establish construction costs with certitude. For the time being, the system is used solely for the exterior walls. The cost for supplying this is $30.70/m2.

The system could also be used for the structure of the floors and the roof with the insertion of trusses or structual roof trusses.

According to the information received from a general contractor, using the sandwich panel systems would cost almost the same as the traditional wood system.

3.2 PRECAST CONCRETE PANELS

This system applies mainly to commercial and industrial construction. The system of precast concrete panels is not used at all on the small house market, since it is not cost competitive. However, the costs of the system were established for the row housing and multi-family models.

The cost of the system includes:

- Prefabricated and insulated exterior wall $120.00/m2
- Composite slabs (concrete and steel) $ 86.00/m2

The differential costs can be explained by:

- Materials and labor necessary for work on the roof, interior stairway, foundation walls.
- Additional gypsum board on metal studs for the interior partitions, on furrings for the exterior walls and ceilings.

4.1 LIGHT PANELS ASSEMBLED BY AUTOMATION

This Swedish system includes all the elements necessary to completely finish a residential unit.

The cost of a system was obtained through an American study. "WHEN THE BEST COST LESS", prepared by Paul F. Kando (#18).

The residential unit which would come closest to the details in our specifications, sold for $83,845.00 (U.S.) in 1988, for 1,865 sq.ft.

To calculate the unit cost, we respected the same ratio as for modular homes, i.e., the first 1,000/sq.ft. or 93/m2 cost a certain amount (X) to build and the additional areas cost 60%.

EXAMPLE

1000 sq.ft. X + 865 sq.ft. (X .6) = $83,845.00
X = $55.00/sq.ft.

Indexed over two (2) years at 5% + 16% exchange rate for the Canadian dollar and we obtain $70.34/sq.ft. or $757.00/m2

For the row housing model, we subtracted 5% = $719.00/m2
For the multi-family model, we subtracted another 5% = $684.00/m2

4.2 MODULES WITH STRUCTUAL STEEL EDGES

Based on a submission prepared by Ortech International, we evaluated the cost of the Japanese system at:

- $ 955.00/m2 for the single detached model
- $1050.00/m2 for the row housing model.

The Japanese principle would seem incompatible with the multi-family model.

APPENDIX "D"

REFERENCES AND CREDITS

List of documents to which reference is made in this report; documents identified in parentheses with the # sign followed by the corresponding number.

1- APPENDIX 1 - PROPOSAL CALL (specifications): A STUDY ON THE COMPARISON OF FACTORY BUILT CONSTRUCTION METHOD AND THE TRADITIONAL ON SITE METHODS; S.H.C. - Analysis and Research Directorate, Montreal, 1990; page 1.

2- INDUSTRIALIZED CONSTRUCTION SYSTEMS IN HOUSING; Roger Bruno RICHARD; S.H.C./M.I.T.C.Q.; Montreal, October 1990; pp. 12 to 14, 43 and 63.

3- CANADIAN WOOD-FRAME HOUSING; C.M.H.C.; Ottawa.

4- DESIGN MANUAL; Association of Concrete Masonry Manufacturers of Quebec; Montreal, 1990.

5- Documents describing the "HAMBRO" system; published by the CANAM Co.

6- THE BUILDING SYSTEMS INTEGRATION HANDBOOK; Richard D. RUSH; John Wiley & Sons; N.Y., 1986; pp. 128 and 129.

7- "HABITABEC MONTREAL" newspaper, January 18, 1991, p. A1.

8- Descriptive documents "BATISSEURS ASSOCIÉS".

9- Documents describing the "THERMOCUBE" and "THERMOMAT" systems published by manufacturers of the same systems.

#10- Descriptive documents published by the distributors of the "INSULWALL" system.

#11- COMPONENT & MODULAR TECHNIQUES: A BUILDER'S HANDBOOK; R.J. LYTLE; McGraw HILL; N.Y., 1982.

#12- Descriptive documents published by the POLYCRETE Co.

#13- Documents describing "PAN-ISOX STRUCTURAL" system.

#14- Descriptive documents published by DESCON INTERNATIONAL (Ottawa).

#15- "COST EFFICIENCY IN CUSTOM DESIGN - THE SWEDISH FACTORY - CRAFTED HOME" published by the Swedish Council for Building Research, Chicago.

#16- Descriptive documents published by the SEKISUI-HAIM Co.

#17- Descriptive documents by the MISAWA HOMES Co.

#18- "WHEN THE BEST COSTS LESS", Paul F. KANDO, published by Swedish Council for Building Research, Chicago.

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- INDUSTRIES BONNEVILLE LTÉE;
- ISO-SAND Inc.;
- MAISONS MODULAIRES TRUDEAU Inc.;
- ORTECH INTERNATIONAL;
- POLYCRETE Distribution (Groupe MEILLEUR);
- SHOCKBETON QUEBEC Inc.;
- STRUCTURES PAQUET (1990) Inc.